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Depositional environments and diagenesis, Interlake Formation (Silurian), Williston Basin, North Dakota

Charles L. LoBue
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Depositional Environments and Diagenesis, Interlake
Formation (Silurian), Williston Basin,
North Dakota

Charles L. LoBue, M.S.

The University of North Dakota, 1983

Faculty Advisor: Professor R. D. LeFever

The Interlake Formation is a succession of Silurian carbonates of large areal extent found in the Williston Basin. The Interlake attains a maximum thickness of about 1,100 feet in western North Dakota and thins to an erosional edge in eastern North Dakota.

The main purpose of this study was to interpret the depositional and diagenetic history of the Interlake Formation. Approximately 2,400 feet of Interlake core and 300 thin sections were studied. The Interlake was then divided into twelve lithotypes representing deposition in low-energy sublittoral, high-energy sublittoral, littoral, and supralittoral epeiric sea environments. In addition, paleosols are present.

Rocks that represent low-energy sublittoral environments contain abundant skeletal allochems, some in growth position. High-energy sublittoral environments are represented by rocks that contain ooids, grapestones, and intraclasts. Peloids, gastropods, intraclasts, and columnar stromatolites are common in rocks from littoral environments. Rocks from supralittoral environments

contain either anhydrite (nodular and laminated) and flat-lying stromatolites or peloids, gastropods, fenestral porosity, together with flat-lying stromatolites. Storm deposits, containing imbricate and abraded skeletal allochems, are found associated with supra-littoral rock types. Hypersaline pond subenvironments of littoral flat complexes are represented by rocks that contain intraclasts, hypersaline ooids, and transported skeletal debris. Paleosols are classified as calcretes and ferricretes and display severe alteration and brecciation of previously deposited Interlake lithologies. The paleosol horizons contain significant amounts of secondary porosity and are good potential reservoir rocks.

Each core studied showed a different vertical succession of lithotypes, with some lithotypes specific to only one core. This extreme variability of lithotypes makes lateral correlation of individual lithotypes impossible. However, correlation of thick successions of littoral flat complex carbonates suggest that littoral flat complexes existed on islands which developed on structurally controlled topographic highs, such as the Nesson and Antelope anticlines, in the Williston Basin.

Local migration of subenvironments and regional migration of major environments on these islands produced the complex mosaic of lithotypes seen in the Interlake. Paleogeographic reconstructions of the Interlake suggest that the islands underwent several stages of inundation, progradation, and prolonged subaerial exposure.

Interlake rocks were dolomitized by hypersaline brines on littoral flat complexes, by mixing of sea water and fresh water in

DEPOSITIONAL ENVIRONMENTS AND DIAGENESIS, INTERLAKE
FORMATION (SILURIAN), WILLISTON BASIN,
NORTH DAKOTA

by
Charles L. LoBue

Bachelor of Arts

Queens College of the City University of New York

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Submitted to the Graduate Faculty

of the

University of North Dakota

in partial fulfillment of the requirements

for the degree of

Master of Science

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This thesis submitted by Charles L. LoBue in partial fulfillment of the requirements for the Degree of Master of Science from the University of North Dakota is hereby approved by the Faculty Advisory Committee under whom the work has been done.

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This thesis meets the standards for appearance and conforms to the style and format requirements of the Graduate School of the University of North Dakota, and is hereby approved.

Dean of the Graduate School

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Title Depositional Environments and Diagenesis, Interlake
Formation (Silurian), Williston Basin, North Dakota

Department Geology

Degree Master of Science

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Date March 31, 1983

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I am especially indebted to my family, whose love and faith were a constant source of strength.

There's nothing constant in the
universe,
All ebb and flow, and every
shape that's born
Bears in its womb the seeds of change.

Ovid,
Metamorphoses, XV(A.D. 8)

ABSTRACT

The Interlake Formation is a succession of Silurian carbonates of large areal extent found in the Williston Basin. The Interlake attains a maximum thickness of about 1,100 feet in western North Dakota and thins to an erosional edge in eastern North Dakota.

The main purpose of this study was to interpret the depositional and diagenetic history of the Interlake Formation. Approximately 2,400 feet of Interlake core and 300 thin sections were studied. The Interlake was then divided into twelve lithotypes representing deposition in low-energy sublittoral, high-energy sublittoral, littoral, and supralittoral epeiric sea environments. In addition, paleosols are present.

Rocks that represent low-energy sublittoral environments contain abundant skeletal allochems, some in growth position. High-energy sublittoral environments are represented by rocks that contain ooids, grapestones, and intraclasts. Peloids, gastropods, intraclasts, and columnar stromatolites are common in rocks from littoral environments. Rocks from supralittoral environments contain either anhydrite (nodular and laminated) and flat-lying stromatolites or peloids, gastropods, fenestral porosity, together with flat-lying stromatolites. Storm deposits, containing imbricate and abraded skeletal allochems, are found associated with supralittoral rock types. Hypersaline pond subenvironments of littoral flat complexes are represented by rocks that contain intraclasts, hypersaline ooids,

and transported skeletal debris. Paleosols are classified as calcretes and ferricretes and display severe alteration and brecciation of previously deposited Interlake lithologies. The paleosol horizons contain significant amounts of secondary porosity and are good potential reservoir rocks.

Each core studied showed a different vertical succession of lithotypes, with some lithotypes specific to only one core. This extreme variability of lithotypes makes lateral correlation of individual lithotypes impossible. However, correlation of thick successions of littoral flat complex carbonates suggest that littoral flat complexes existed on islands which developed on structurally controlled topographic highs, such as the Nesson and Antelope anticlines, in the Williston Basin.

Local migration of subenvironments and regional migration of major environments on these islands produced the complex mosaic of lithotypes seen in the Interlake. Paleogeographic reconstructions of the Interlake suggest that the islands underwent several stages of inundation, progradation, and prolonged subaerial exposure.

Interlake rocks were dolomitized by hypersaline brines on littoral flat complexes, by mixing of sea water and fresh water in the shallow subsurface, and by pressure solution after deep burial. Porosity in the Interlake formed during depositional (interparticle) and eogenetic (fenestral, vugular) diagenetic stages. Fibrous and bladed calcite cements occlude primary porosity and formed in marine phreatic environments. Equant calcite cement formed in meteoric phreatic environments. Saddle dolomite cement formed after deep burial of Interlake rocks.

INTRODUCTION

General

The Interlake Formation is a succession of Silurian carbonates of large areal extent found in the Williston Basin. It was named for exposures in the Interlake area of Manitoba (Baillie, 1951); usage was subsequently extended into the subsurface of Manitoba, Saskatchewan, Montana, and North Dakota by Porter and Fuller in 1959. The Interlake is composed largely of dolostone, with subordinate amounts of limestone, anhydrite, and chert. It attains a maximum thickness of about 1,100 feet in western North Dakota and thins to zero along its erosional edge (Fig. 1) in eastern North Dakota (Carlson and Eastwood, 1962, p. 12).

Although the Interlake Formation has been a consistent oil producer in North Dakota, with two new discoveries in 1981 (Anderson and Bluemle, 1982), no extensive petrographic studies have been done on this formation in the state.

Purpose of Study

The purpose of this study is: 1) to conduct detailed petrographic study of the lithologies in the Interlake Formation; 2) to interpret the depositional environments during Interlake time; 3) to develop environmental models for these rocks; 4) to interpret the depositional history of the Interlake; and 5) to determine the diagenesis and paragenesis of the Interlake rocks.

Tectonic History and Early Basinal History

The Williston Basin is a sedimentary and structural basin with a thickness of up to 15,000 feet of sedimentary rocks of Phanerozoic age, covering some 51,600 square miles of North Dakota as well as parts of South Dakota, Montana, Manitoba, and Saskatchewan (Carlson and Anderson, 1965).

The boundary between the Precambrian Churchill and Superior structural provinces trends north-to-south through central North Dakota and into Manitoba. This is probably the eastern hinge line for the Williston Basin (Gerhard et al., 1982, p. 991).

The Williston Basin contains several minor structures. In North Dakota these consist of several anticlines, lineaments, and highs (Fig. 2). These structures may be the result of movement of basement blocks which became structurally defined in Precambrian time (Gerhard et al., 1982, p. 1000) and may have influenced sedimentation in the basin throughout Phanerozoic time (Gerhard et al., 1982, p. 993).

During Early Paleozoic time the Williston Basin did not exist, but was only an indentation in the northern North American craton shelf (Gerhard et al., 1982, p. 999). Active subsidence in the Williston Basin began during Early Ordovician time initiating a transgressive event that was fairly continuous from Middle Ordovician through Early or Middle Silurian time. The Middle Ordovician Winnipeg Group, which consists of a lower sandstone overlain by shales, is the basal transgressive unit in this sequence. The overlying Ordovician carbonates and shales and Silurian carbonates

Figure 1. Isopach map of the Interlake Formation in North Dakota. Modified from Carlson and Eastwood (1962).

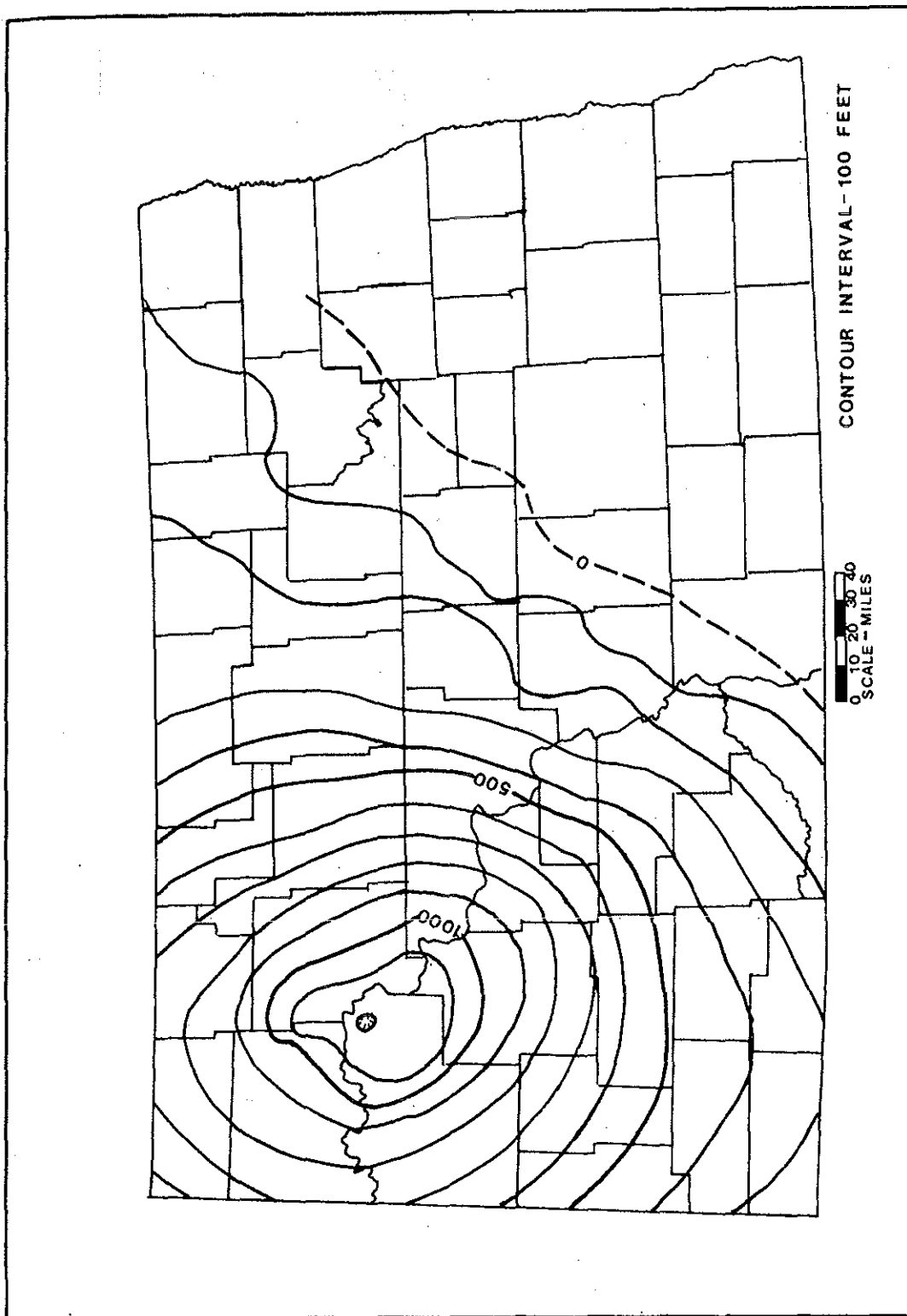
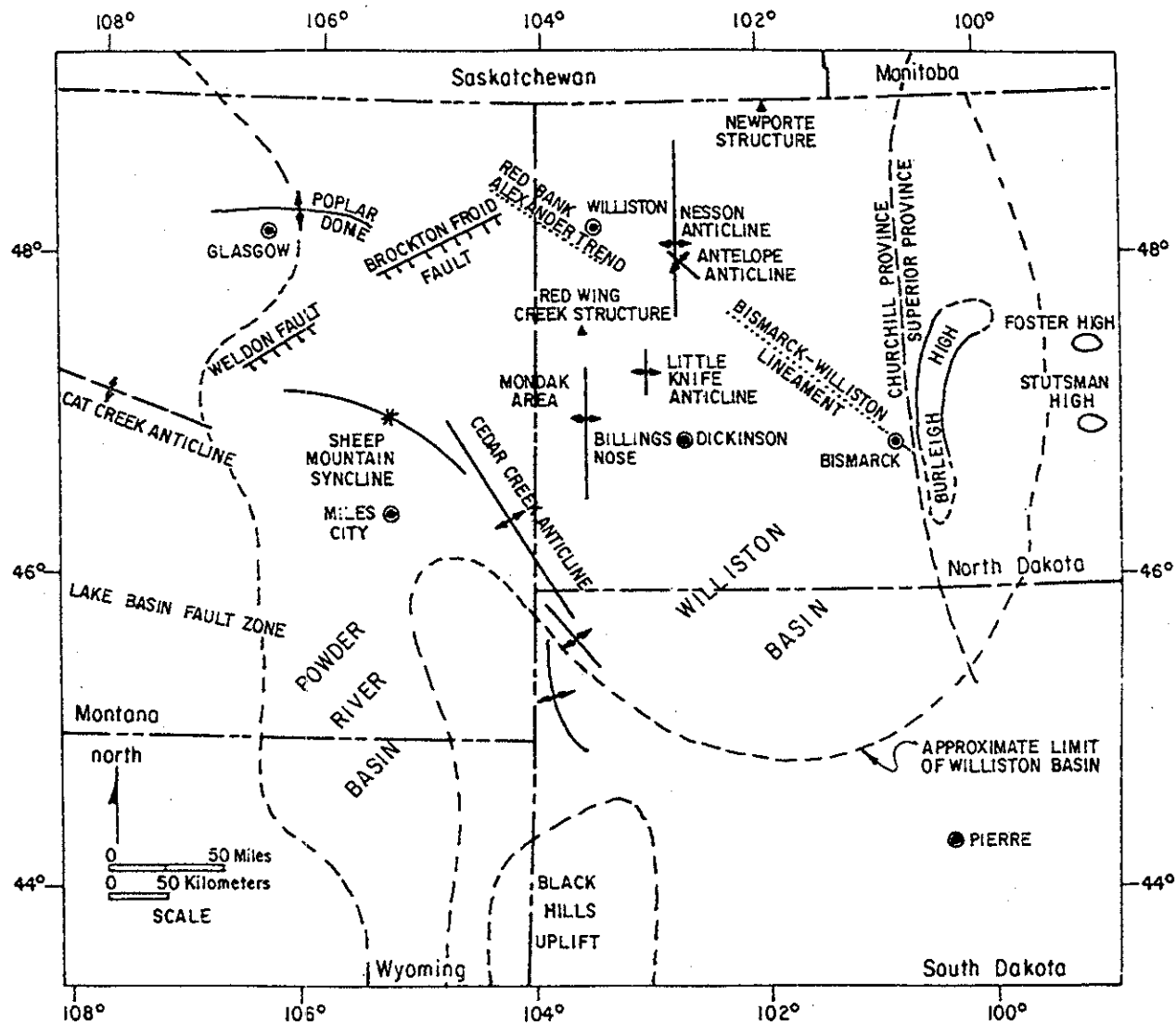


Figure 2. Major structures of the Williston Basin.
Reproduced from Anderson and Blumle (1982)
with permission of the authors.



reflect continuing deposition in warm, shallow seas and associated subaerial environments which existed in North Dakota during this time (Gerhard et al., 1982, p. 994).

Previous Work and Stratigraphy

Previous Work

Rocks now ascribed to the Interlake Formation were first described in western Manitoba by Kindle (1913) who referred to the entire Silurian section as the Stonewall Limestone. The name Interlake Group was first proposed by Baillie (1951) for the sequence of carbonate rocks which crop out in the Interlake area of Manitoba, underlie the Ashern Formation of Late Silurian or Early Devonian age and overlie the Ordovician Stony Mountain Formation (Table 1). Baillie considered structures in the Silurian carbonates in Manitoba, such as mud-cracked and stromatolitic rocks, to be analogous to structures on tidal flats on Andros Island in the Bahamas. Although Baillie was not able to outline a depositional history for the Interlake, he suggested that abundant coral reefs of considerable lateral extent and restricted vertical extent existed in a warm, shallow sea which covered southern Manitoba during Silurian time.

Stanton (1953) studied the Interlake in western Saskatchewan and concluded that it represented deposition on the shelf area of an extensive, shallow sea which covered southern Saskatchewan during Silurian time. Within that sea, reefs of colonial corals were common; because the sea was so shallow, the coral reefs grew laterally to form biostromal sheets. Stromatolites were also common. Stanton also suggested that lithographic dolomite and anhydrite

Table 1. Upper Ordovician and Silurian correlation chart, Williston Basin, showing Manitoba, Saskatchewan, Montana, and North Dakota subsurface and Manitoba outcrops. Modified after Roehl (1967).

UPPER ORDOVICIAN - SILURIAN CORRELATION CHART, UNITED STATES AND CANADA									
		Porter-Fuller '59	Stearn 1956	Baillie 1951	Cowan 1971	This paper			
		Manit., Sask., N. Dak., Mont. Subsurface	Manitoba Outcrops	Manitoba Outcrops	Manitoba Subsurface	North Dakota Subsurface			
UPPER ORDOVICIAN	MIDDLE SILURIAN	Interlake Group	Upper Interlake						
			Middle Interlake	Interlake Gp.	Cedar Lake	Interlake Gp.	Cedar Lake	Interlake Formation	
					East Arm				
					Atikameg				
					Moose Lake		Brandon		
			Lower Interlake		Inwood		Strathclair		
					Fisher Lake				
		Stony Mtn. Formation	Stonewall Formation					Stonewall Formation	
				Interlake Group	Unit E				
					Unit D				
					Unit C				
					Unit B				
			Gunton Member	Stony Mtn. Formation	Stonewall Formation				
		Stony Mtn. Shale			Gunton Member			Stony Mtn. Formation	Gunton Member
					Penitentiary Member				Stoughton Member
					Stony Mtn. Shale			Red River Formation	
		Red River Formation		Red River	Selkirk Mem.			Red River Formation	
					Cathead Mem.				
					Doghead Mem.				

indicated the existence of hypersaline conditions.

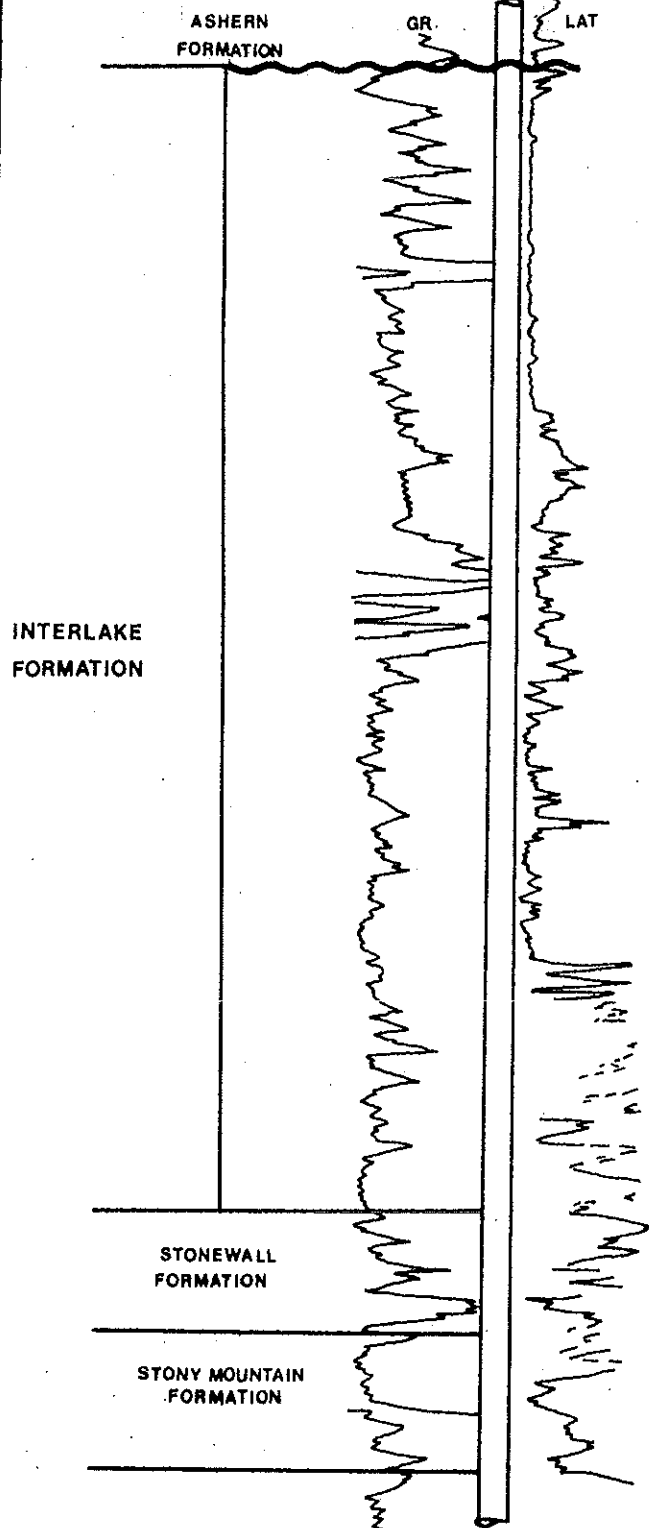
Stearn (1956) studied the Interlake in southern Manitoba and, using lithologic distinctions in outcrop, divided the Interlake into six formations which are, in ascending order, the Fisher Lake, Inwood, Moose Lake, Atikameg, East Arm, and Cedar Lake Formations. He also suggested that the Stonewall Formation be separated from the Interlake Group.

Porter and Fuller (1959) conducted an extensive subsurface study of the Interlake in southern Manitoba, southern Saskatchewan, eastern Montana, and North Dakota. They divided the Interlake, on the basis of mechanical log data, into three intervals, "Lower", "Middle", and "Upper", separated by strong gamma-ray deflections which are anomalous in the typically quiet log signature of the Interlake carbonates (Fig. 3). They also suggested separating the Stonewall Formation from the Interlake Group. They concluded that the Interlake is composed of a uniform dolomitic mudstone that represented mud deposited in a warm, shallow sea that existed in North Dakota and the remainder of their area of study during Silurian time. Small reef-building colonies abounded in this sea. Many thin gamma-ray deflections interpreted as sandy layers in the Interlake, were used as para-time markers by these authors.

Andrichuck (1959) revised Baillie's work in southern Manitoba but, unlike previous workers, he preferred to include the Stonewall Formation as part of the Interlake Group. He concluded that the lower part of the Interlake represented mud that precipitated on a bank behind carbonate build-ups, which restricted circulation of water

Figure 3. Gamma ray log and lateral log of Interlake, Stonewall, and Stony Mountain Formations, western North Dakota. Note well-developed deflection on the gamma-ray log near the middle of the Interlake Formation.

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NDGS 1385



of normal salinity in the shallow sea which covered that area during Silurian time. This restriction resulted in hypersaline conditions which caused penecontemporaneous dolomitization of the lime mud. Andrichuck also described the upper portions of the Interlake as a coarse-grained limestone, but offered no environmental interpretation.

Carlson and Eastwood (1962) conducted the first detailed study of the Interlake in North Dakota. They relegated the Interlake to formational rank and agreed with Porter's and Fuller's (1959) separation of the Interlake and Stonewall Formations. They concluded that the Interlake represented deposition in a shallow, slightly hypersaline sea that covered North Dakota during Silurian time. They suggested that the lower Interlake represented quiet conditions which resulted in deposition of mud and anhydrite while the upper portions were deposited under higher-energy conditions which formed "pseudo-ooids" and pellets.

King (1964) revised the work of Porter and Fuller (1959) and Andrichuck (1959) in the subsurface of southern Manitoba. He divided the Interlake into three formations. They are, in ascending order, the Strathclair, Brandon, and Cedar Lake Formations. He interpreted the lower Interlake as a shallow water deposit in which isolated reef complexes developed. Subsequent higher-energy conditions resulted in the formation of ooids along with reefs in the middle part of the section, with dolomitic mud and terrigenous material deposited in more restricted areas. King also concluded that upper Interlake rocks contained patch reefs which were killed off by fluctuations in

sea level.

Although Baillie (1951) had suggested an analogy between structures in carbonates of the Interlake Formation and structures on Andros Island tidal flats, Roehl (1967) was the first worker to rigorously apply modern analogs to Silurian rocks in the Williston Basin. Using core taken along the Cedar Creek anticline in southeastern Montana, Roehl demonstrated a marked similarity between facies and fabrics developed in the tidal flats of Andros Island in the Bahamas and those developed in Interlake carbonates. This was the first suggestion that tidal flat deposition was an important component in Interlake sedimentation. Because of the restricted nature of Roehl's study, however, his data cannot be considered to characterize the entire Williston Basin.

Cowan (1971) revised the work done on the Interlake in southern Manitoba. He continued King's (1964) subdivisions of the Interlake and also extended Roehl's (1967) depositional environments into Manitoba.

The most recent work on the Interlake was done in southern Saskatchewan by Magathan (1979) and in western North Dakota by LoBue (1982). Both of these works will be considered in the depositional history and paleogeographic reconstruction section of this paper.

With the exception that the Ashern is here considered to be a formation, North Dakota Geological Survey stratigraphic subdivisions (Bleumle et al., 1980) are used in this paper. The

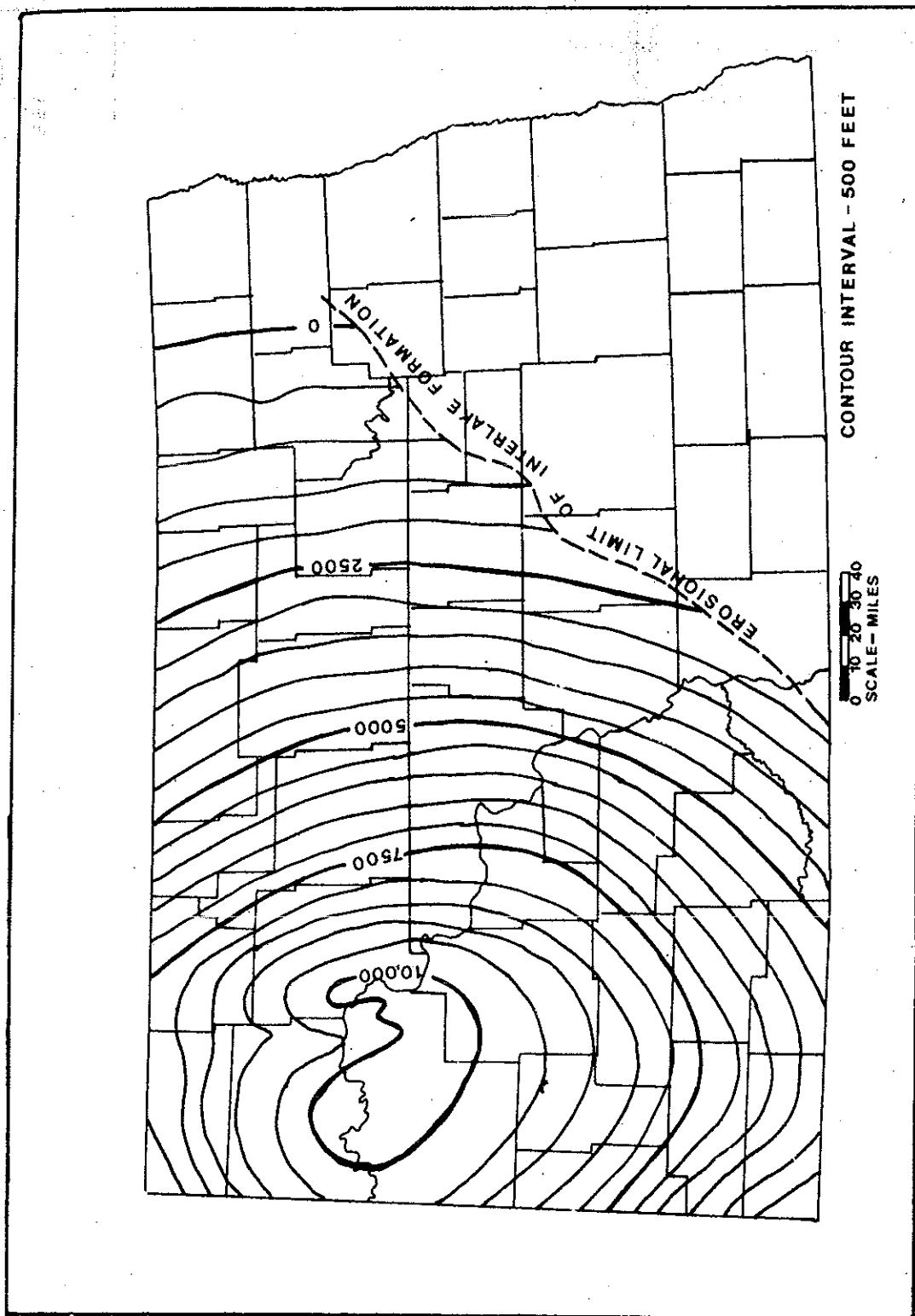
Interlake is considered as a formation while the Stonewall Formation is included in the Big Horn Group with the Stony Mountain and Red River Formations (Table 1). No formal subdivisions of the Interlake are recognized.

Stratigraphy

The Upper Ordovician-Lower Silurian Stonewall Formation conformably underlies the Interlake Formation (Fig. 3). In northwestern North Dakota, the Stonewall consists of a thin bed of anhydrite at the base, overlain by gray and brownish-gray finely crystalline limestone and dolomitic limestone which contains thin-bedded anhydrite (Carlson and Eastwood, 1962, p. 9).

A structure contour map (Fig. 4) of the top of Interlake Formation shows that several contours are truncated by the erosional limit of the Interlake. This suggests that pre-Devonian erosion removed large amounts of Silurian material (Carlson and Anderson, 1965, p. 1837; Lobdell, personal communication, 1982). The Ashern Formation, presumably of Early Devonian age overlies a karst surface on the Interlake, marking one of the major unconformities in the Williston Basin (Roehl, 1967, p. 1982). The Ashern Formation consists of a lower red member and an upper gray member, both composed of dolostone with some nodular anhydrite in the lower red member. The red beds were formed in the supratidal environment and the overlying gray beds in low intertidal to subtidal environments (Lobdell, 1982).

Figure 4. Structure contour map of the Interlake Formation in North Dakota. Datum is the top of the Interlake Formation. Modified from Carlson and Eastwood (1962).



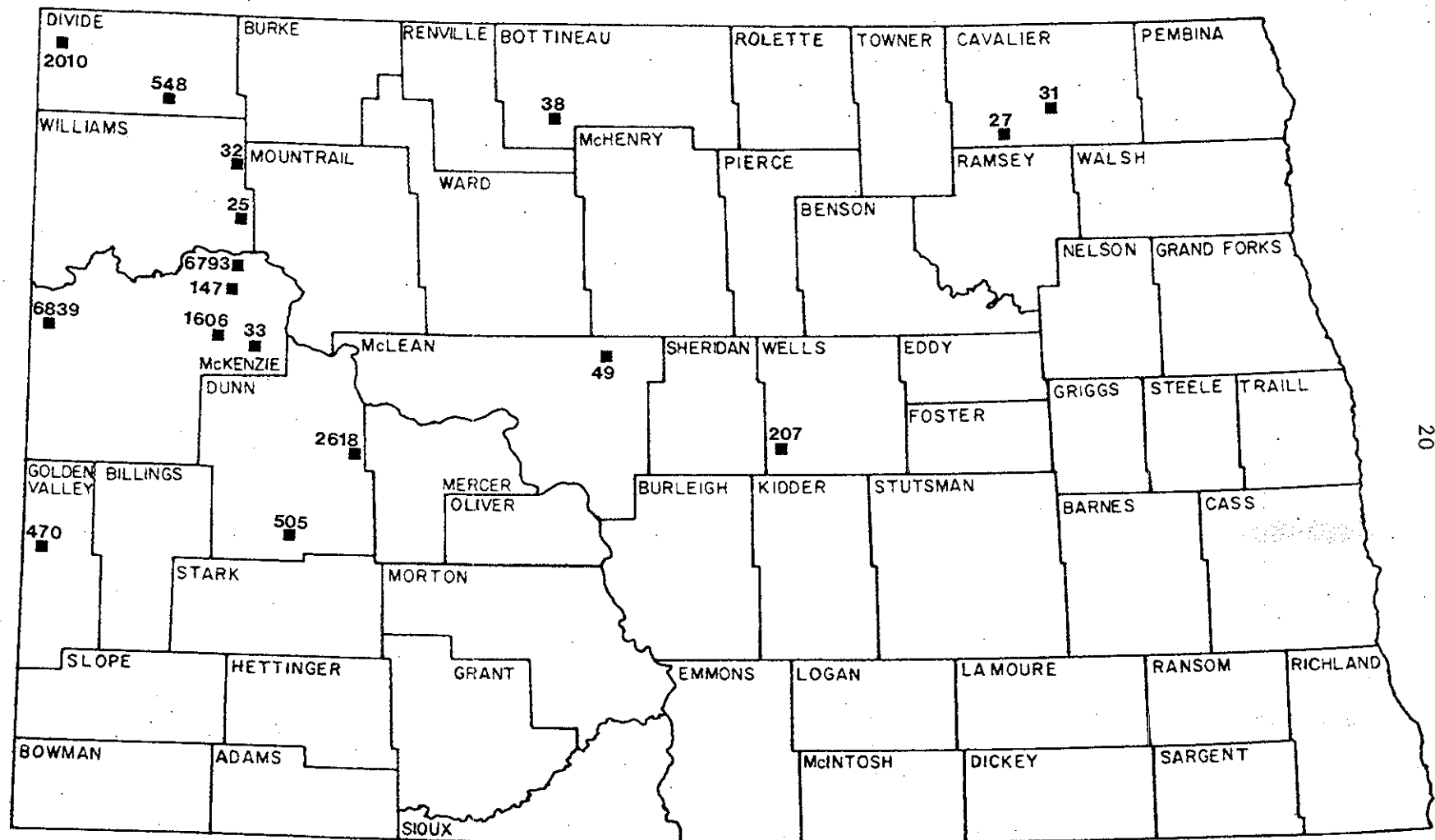
METHOD OF STUDY

The study was confined to the state of North Dakota. The major source of data was core housed at the Wilson M. Laird Core and Sample Library maintained by the North Dakota Geological Survey, Grand Forks; the distribution of cores used is shown on Figure 5.

Wells are cited in the text by North Dakota Geological Survey (NDGS) well number (e.g. Blanche Thompson No. 1 = NDGS 38). Legal descriptions for wells cited in the text are given in Appendices A and B. A reflected light microscope and a hand lens were used for macroscopic analysis of 2400 feet of core. Reflected light and polarizing microscopes were used for detailed petrographic analysis of 300 thin sections (appendix B). To distinguish calcite from dolomite, thin sections were stained in a solution of alizarin red S as described by Friedman (1971).

Thin sections and cores were described using the nomenclature of Dunham (1962) with descriptive modifiers proposed by Folk (1959). Diagenetic textures and environments were described using Folk (1965) and Longman (1980) respectively. The terminology applied to the porosity is that of Choquette and Pray (1970) and Grover and Read (1978).

Figure 5. Distribution of core used in this study.



LITHOTYPE DESCRIPTIONS

Introduction

As a result of this study Interlake rocks are divided into the following twelve lithotypes: 1) pelmatozoan anthozoan wackestone; 2) ooid grainstone; 3) peloidal quartz silt packstone; 4) fenestral peloidal wackestone; 5) ooid intraclastic wackestone; 6) trilobite mudstone; 7) intraclastic pelmatozoan wackepackstone; 8) stromatolite and cryptalgal dololaminate; 9) anhydritic dolomitic mudstone; 10) mudstone; 11) ferruginous dolostone and limestone; and 12) brecciated dolostone.

These lithotypes were recognized on the basis of information obtained from detailed petrographic analysis of core samples and thin sections (see appendix B). Each lithotype was defined on the basis of features common to a variety of rocks; the descriptive modifiers employed to define these lithotypes refer to the dominant allochems or other dominant features.

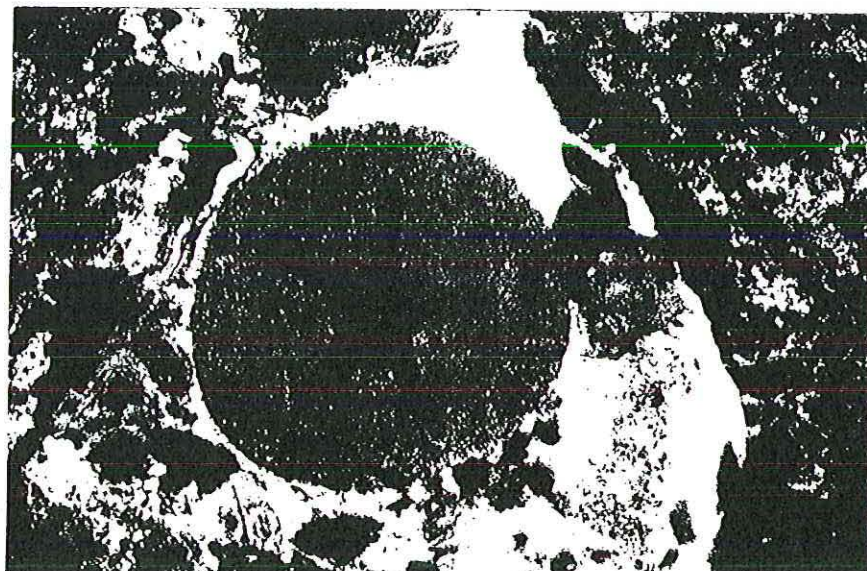
Each core studied showed a different vertical succession of lithotypes, with some lithotypes occurring in only one core. Therefore, the succession of lithotypes in the Interlake exhibits extreme lateral and vertical variability, thus making correlation difficult. In general, carbonate mudstone content in the Interlake Formation increases from southwest to northeast in North Dakota. Mudstone, and stromatolite and cryptalgal dololaminate are the

Figure 6. Pelmatozoan Anthozoan Wackestone Lithotype.

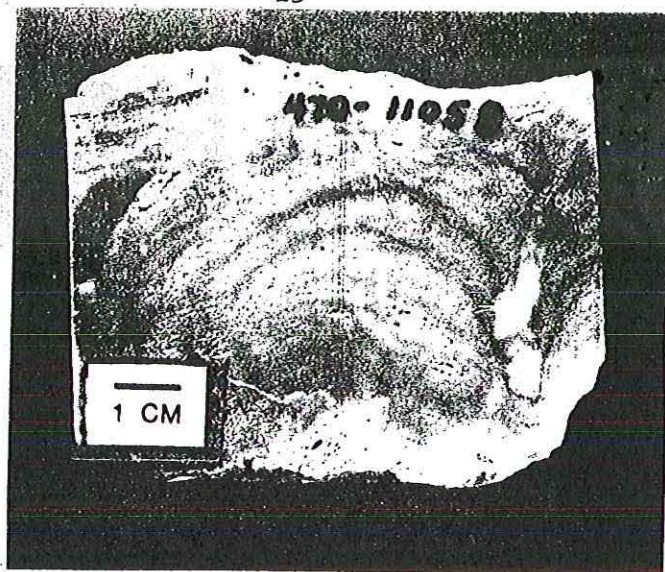
- A) Photomicrograph of a tabulate (favositoid) coral. Length of bar is 1 mm. Thin section no. 38-6858.
- B) Photomicrograph of a pelmatozoan echinoderm columnal (a). Length of bar is 1 mm. Thin section no. 38-6858.
- C) Photograph of a hemispherical stromatoporoid. Core no. 470-11059.
- D) Photomicrograph of a stromatoporoid showing pillars (a). Length of bar is 1 mm. Thin section no. 38-6858.
- E) Photomicrograph of calcareous (codiacian?) algae (a). Length of bar is 1 mm. Thin section no. 38-6858.



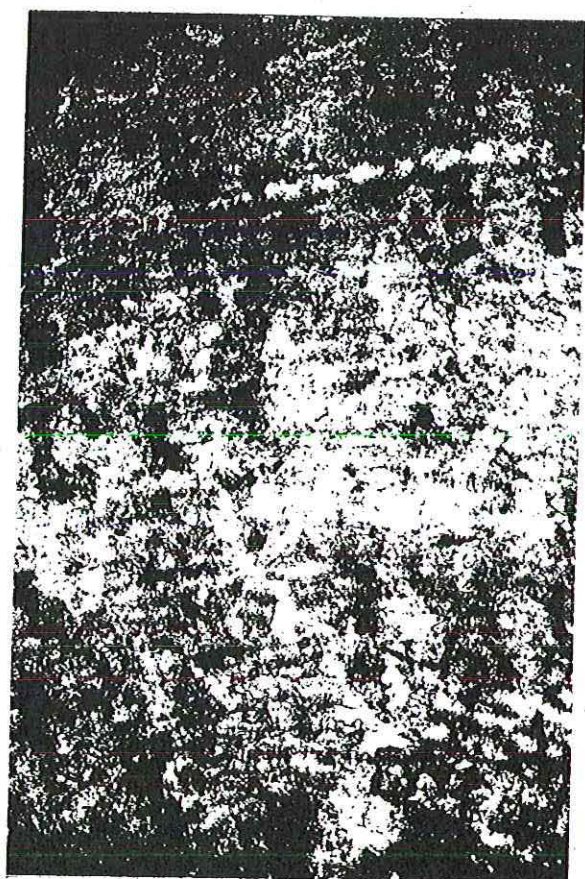
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Some skeletal allochems are micritized.

Ooid Grainstone

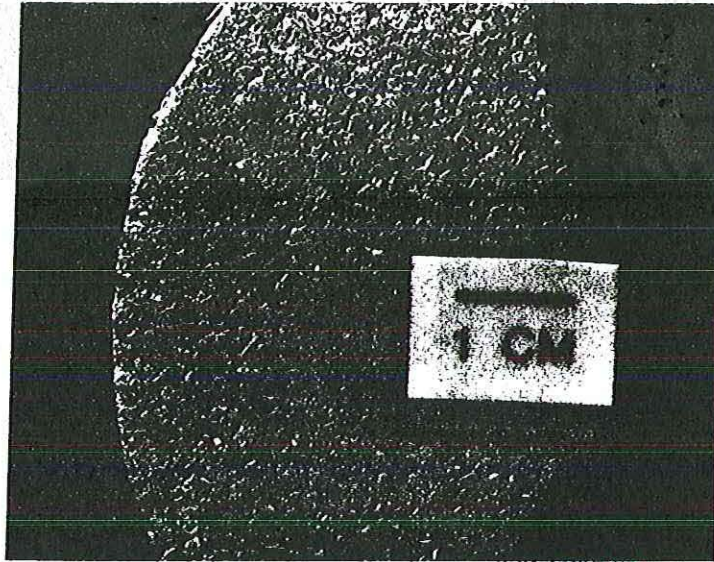
Rocks of the ooid grainstone lithotype are pale gray to tan, well sorted, and are composed mainly (70 to 90 percent) of ooids which exhibit conspicuous concentric laminations and have cores which appear to be mudstone clasts (Fig. 7A and 7B). Other allochems, in order to decreasing abundance, are pisolites, grapestones (averaging 4 mm in longest dimension) (Fig. 7C), elongate intraclasts (ranging from 2 mm to 3 cm in longest dimension (Fig. 7D), peloids (averaging 1-2 mm in diameter), disarticulated and broken brachiopod shells, dendritic stromatoporoids (Fig. 7E), and blue-green algal biscuits and oncolites (averaging 4 mm in transverse dimension and 1 mm thick). Locally, ooids form conspicuous ripples (Fig. 7F). Mineralogically, rocks of the ooid grainstone lithotype are composed of dolomitic calcite.

Peloidal Quartz Silt Packstone

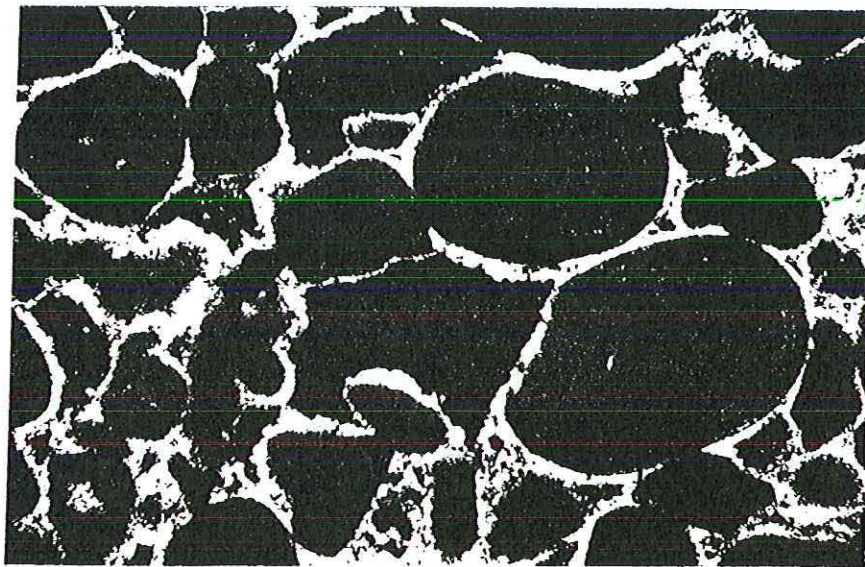
Rocks of the peloidal quartz silt packstone lithotype are light gray and tan to pinkish-tan packstones (grainstone or wackestone locally), composed of dark gray to tan, well-rounded peloids 250-300 microns in diameter (Fig. 8A). These peloids, which make up about 80 to 95 percent of the allochems of this lithotype, are featureless, opaque, and are commonly in either point or long contact with adjacent grains. Other allochems, in order of decreasing abundance, are well-rounded quartz sand and silt (Fig. 7B), rounded intraclasts (3-5 mm in longest dimension (Fig. 8C),

Figure 7. Ooid Grainstone Lithotype.

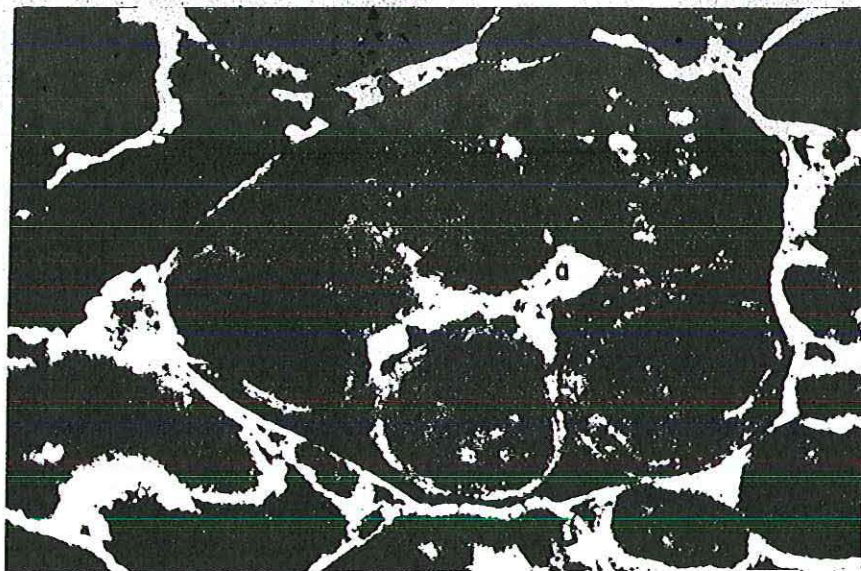
- A) Photograph of ooids (a) and grapestones (b).
Core no. 31-1951A.
- B) Photomicrograph of ooids showing
concentric laminations (a). Length of
bar is 1 mm. Thin section no. 31-1954B.
- C) Photomicrograph of a grapestone (a).
Length of bar is 1 mm. Thin section no.
31-1954B.
- D) Photomicrograph of intraclasts (a).
Core no. 27-2431.
- E) Photomicrograph of a stromatoporoid (a).
Length of bar is 1 mm. Thin section
no. 31-1973A.
- F) Photograph of ripples. Core no.
31-1950A.



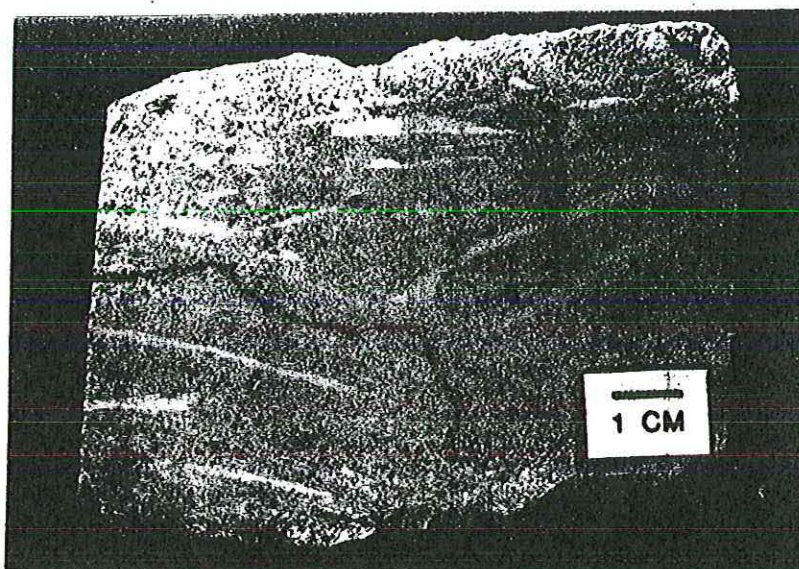
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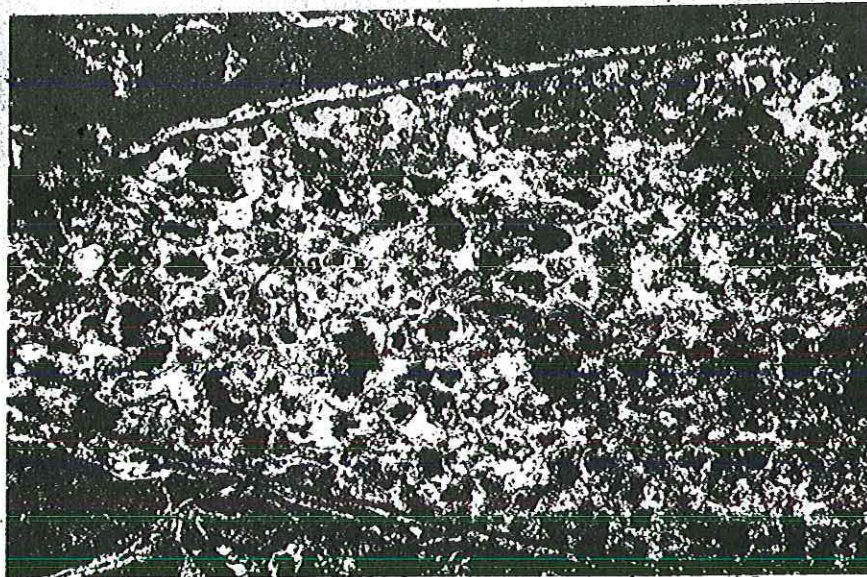
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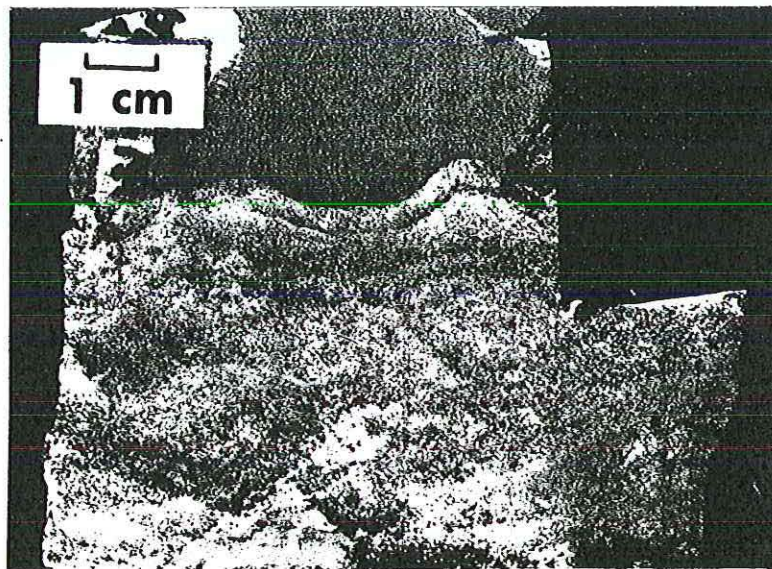
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and low-spined, ornate gastropods 2-3 mm long (Fig. 8D). Locally, quartz silt makes up as much as 10 to 20 percent of the rock, with quartz sand usually comprising less than 1 or 2 percent.

Gastropod shells are only locally abundant and are normally whole but also may be broken. The allochems are generally well sorted. Matrix, where present, is composed of gray dolomitic mudstone. In some places, thin beds of dolomitic mudstone are present, but sedimentary structures are generally absent. Mineralogically, the carbonate allochems in this lithotype are composed entirely of dolomite, which is microcrystalline, except gastropod shells which are composed of coarser-grained dolomite (Fig. 8D).

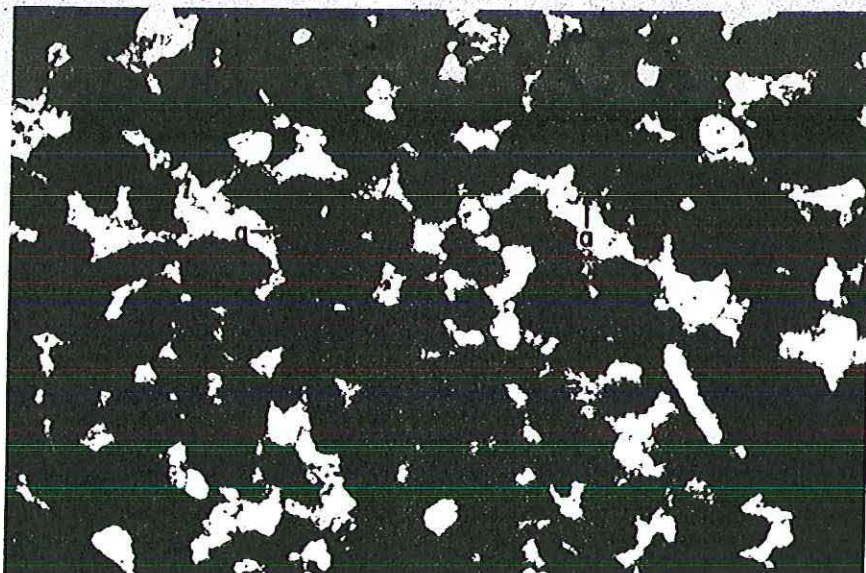
Fenestral Peloidal Wackestone

Rocks in the fenestral peloidal wackestone lithotype are tan to gray or red and are characterized by well-developed fenestral porosity (Fig. 9A). Peloids, which comprise 80 to 90 percent of the allochems in this lithotype, are well rounded and range from 175 microns to 300 microns in diameter. Other constituents, in order of decreasing abundance, are dark gray, equant, angular intraclasts, which average 0.8 mm in diameter, rounded quartz silt, small gastropods 2-3 mm long, and ostracods. The matrix is either calcareous or dolomitic mudstone which commonly contains laminations.

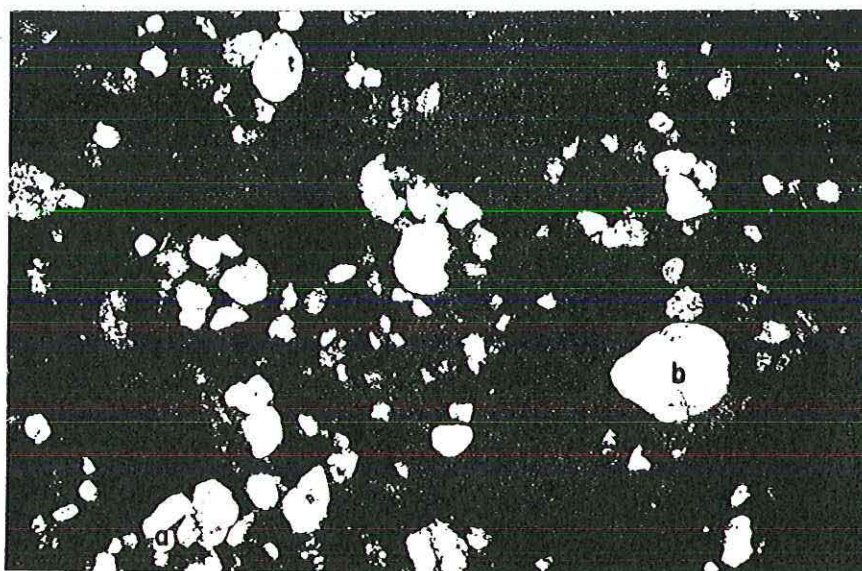
Erosion surfaces are common in this lithotype and are marked by truncation of laminae, draping of overlying laminae on an irregular surface, and rip-up clasts (Fig. 9B and 9C). Carbonate allochems in the fenestral peloidal wackestone lithotype are composed of microcrystalline dolomite, but locally are composed of micrite.

Figure 8. Peloidal Quartz Silt Packstone Lithotype.

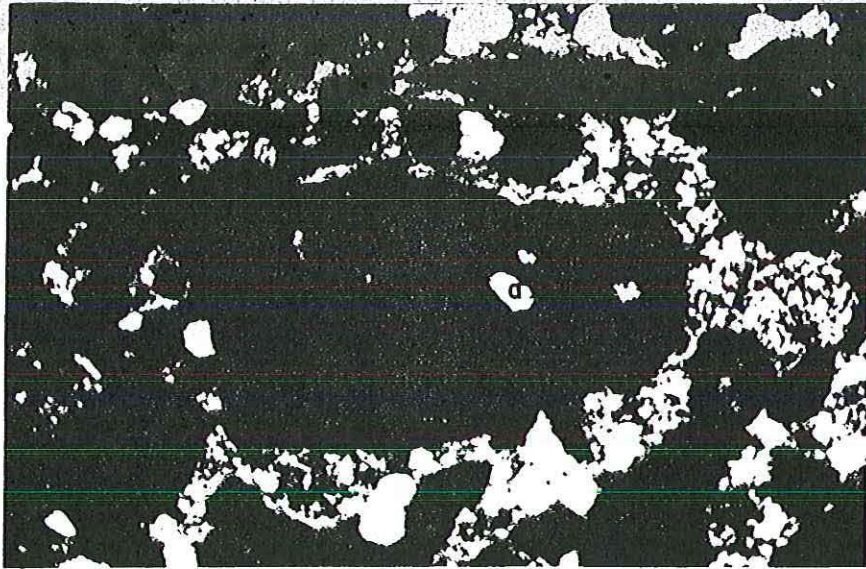
- A) Photomicrograph of peloids (a). Length of bar is 1 mm. Thin section no. 147-12273½.
- B) Photomicrograph of quartz silt (a) and sand (b). Length of bar is 1 mm. Thin section no. 33-12683.
- C) Photomicrograph of intraclasts (a). Length of bar is 1 mm. Thin section no. 33. 12683.
- D) Photomicrograph of gastropod replaced by dolomite. Length of bar is 1 mm. Thin section no. 147-12273½.



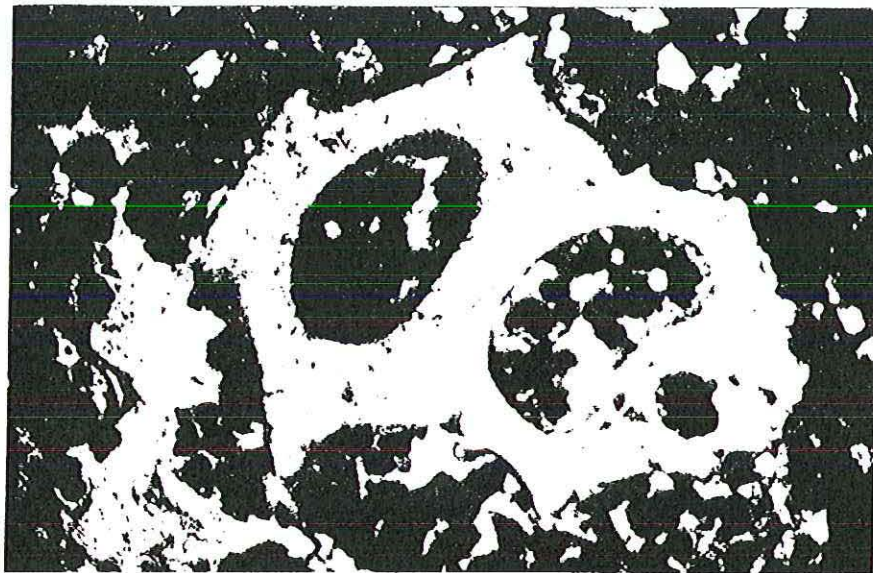
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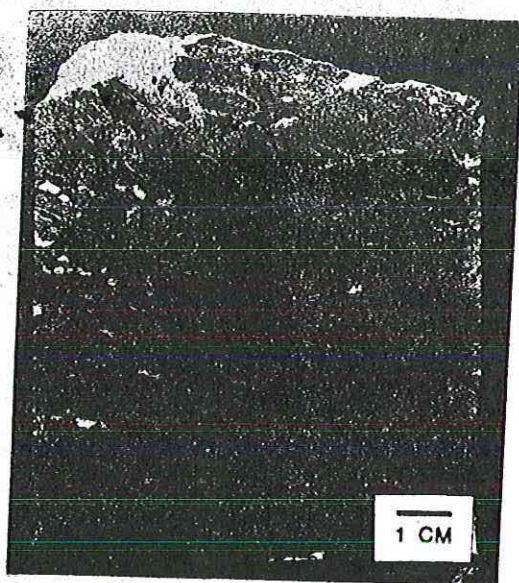
Morphology of the fenestral pores in this lithotype is complex, but can be divided into two basic types using the terminology of Grover and Read (1979). These are irregular fenestrae and laminoid fenestrae (Fig. 9D). Irregular fenestrae are the most common type in this lithotype and occur in a wide variety of shapes and sizes. These shapes include amoeboidal, arcuate, irregularly ellipsoidal, or nearly spherical. The irregularly ellipsoidal type is as large as 4 mm long and 1 mm wide. All other irregular fenestrae are 1 mm or less in all dimensions. Laminoid fenestrae are less variable than the irregular types, mostly occurring as a series of closely spaced (0.25 mm), subhorizontal pores 1-3 microns in height. These fenestrae are discontinuous, rarely exceeding 1 mm in length and are commonly bifurcated. Locally, laminoid fenestrae have formed concentrically around larger irregular fenestrae. Geopetal infill, usually mud which may contain ostracods, is common in fenestral porosity (Fig. 9E).

Ooid Intraclastic Wackestone

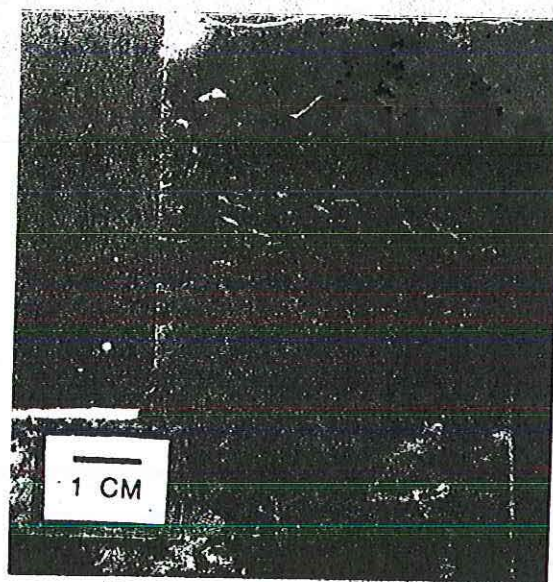
Rocks of the ooid intraclastic wackestone lithotype are tan, poorly sorted, and contain about 20 percent elongate mudstone lithoclasts and about 10 percent ooids in a clotty, peloidal, dolomitic, mudstone matrix (Fig. 10A). The intraclasts, which are composed of dolomitic mudstone, are well rounded and have gray exteriors grading into tan interiors. They range from 2 mm to 9 mm thick and from 0.5 cm to 2.5 cm long and are either parallel or subparallel to bedding. Ooids range in size from 0.1 mm to 0.7 mm

Figure 9. Fenestral Peloidal Wackestone Lithotype.

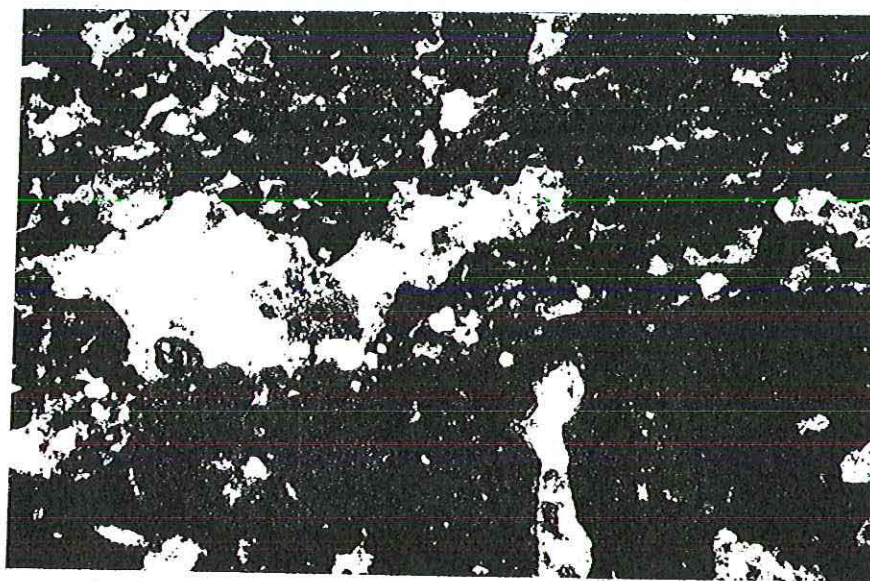
- A) Photograph of slab with fenestral porosity (a) infilled with calcite cement. Core no. 147-12257.
- B) Photograph of erosion surface (a) and rip-up clasts (b). core no. 33-12647.
- C) Photomicrograph of erosion surface (a). Length of bar is 1 mm. Thin section no. 33-12647.
- D) Photomicrograph of irregular (a) and laminoid (b) fenestrae. Length of bar is 1 mm. Thin section no. 147-12265½.
- E) Photomicrograph of geopetal infill consisting of ostracods (a) and mudstone (b). Length of bar is 1 mm. Thin section no. 505-350.



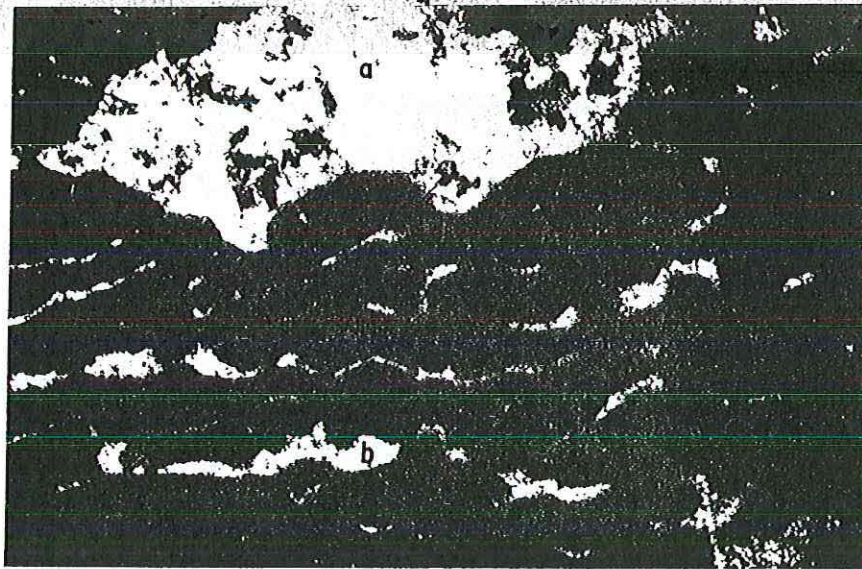
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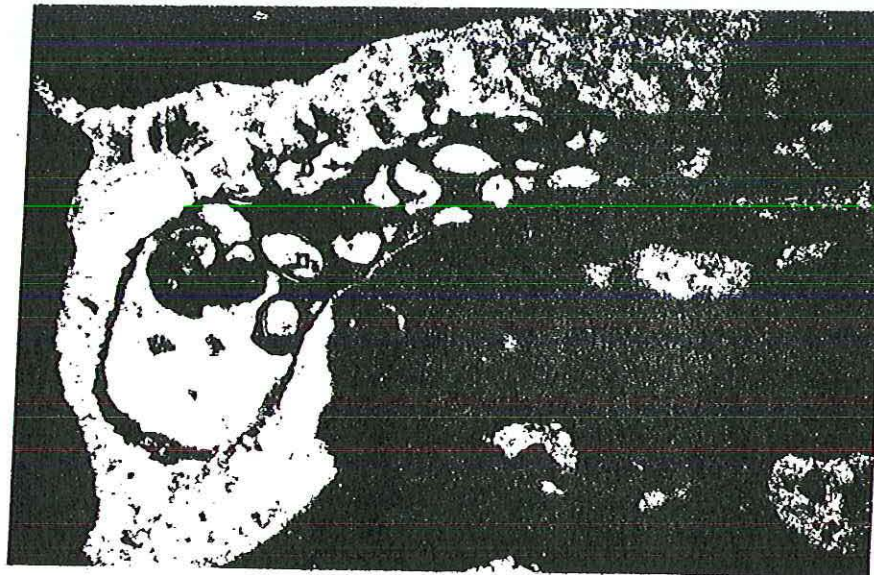
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in diameter and display a well-developed, radial fibrous microstructure (Fig. 10B). About half of the ooids contain one or two well-developed, dark, concentric laminae although a few have as many as six (Fig. 10B). The peloids in the mudstone matrix are small (62-88 microns in diameter), spherical, and opaque. All allochems and matrix are composed of dolomite.

Trilobite Mudstone

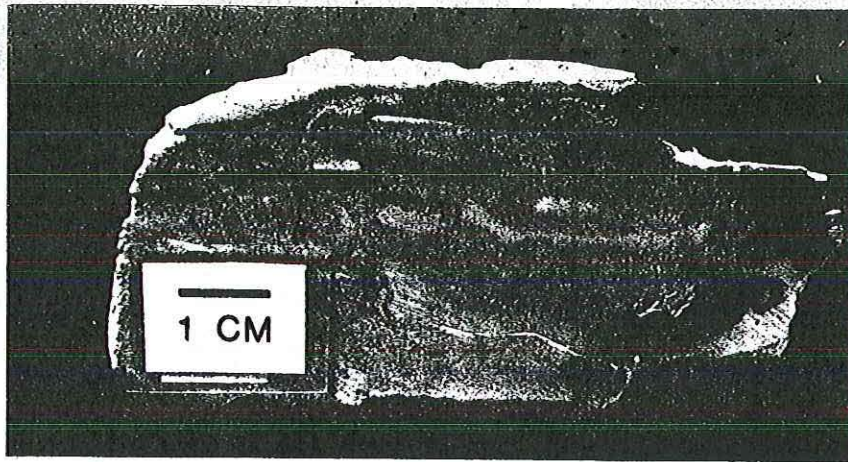
Rocks of the trilobite mudstone lithotype are composed of grayish-black, gray, or pinkish-gray micrite containing less than 10 percent trilobite fragments. These fragments average 1 mm in length and may rarely be concentrated into 2 mm-thick packstone layers (Fig. 11A), with the elongate fragments parallel or subparallel to bedding. The grayish-black micrite contains only trilobites while the gray and pinkish-gray varieties also contain about 1 or 2 percent ostracods, and fragments of small gastropods and calcispheres (Fig. 11B).

Intraclastic Pelmatozoan Wackepackstone

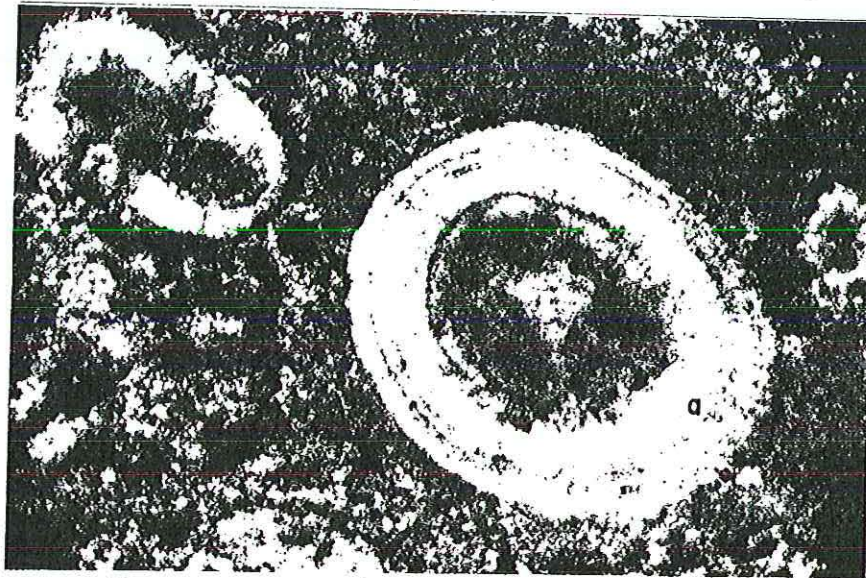
Rocks in the intraclastic pelmatozoan wackepackstone lithotype vary from dark brown to tan and are composed of imbricate skeletal hash (Fig. 12A). Intraclasts (Fig. 12B) and pelmatozoan columnals (Fig. 12C) are the most common allochems comprising about 75 percent (total allochems) of the rocks in this lithotype. The intraclasts are elongate to equant in shape and range in size from 2 mm to 1 cm in longest dimension. They are generally composed of micrite although a few contain 5 to 10 percent ostracods. The

Figure 10. Ooid Intraclastic Wackestone Lithotype.

- A) Photograph of intraclasts (a). Core no. 38-7000.
- B) Photomicrograph of ooids (a) displaying a radial fibrous microstructure. Length of bar is 1 mm. Thin section no. 38-7000.



A



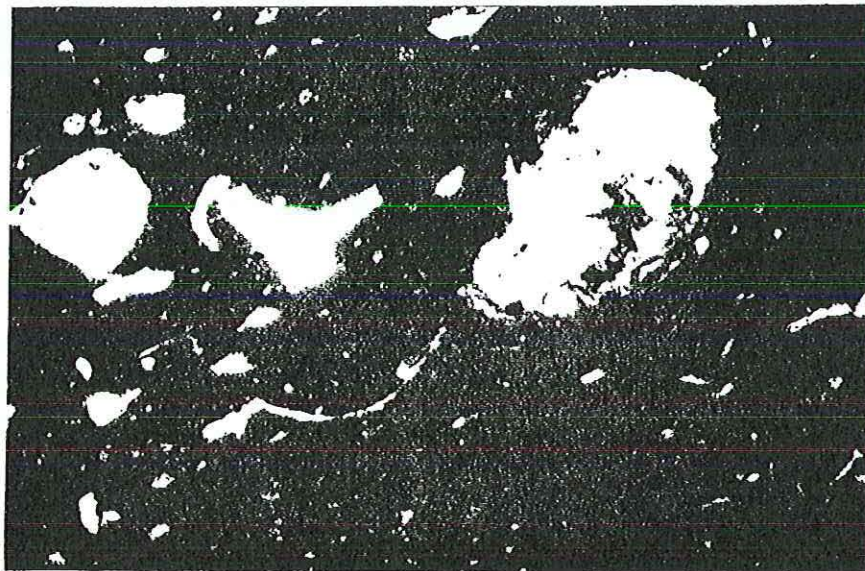
B

Figure 11. Trilobite Mudstone Lithotype.

- A) Photomicrograph of trilobite hash. Length of bar is 1 mm. Thin section no. 1606-12763½.
- B) Photomicrograph of gastropods (a) and ostracods (b). Length of bar is 1 mm. Thin section no. 1606-12754.



A



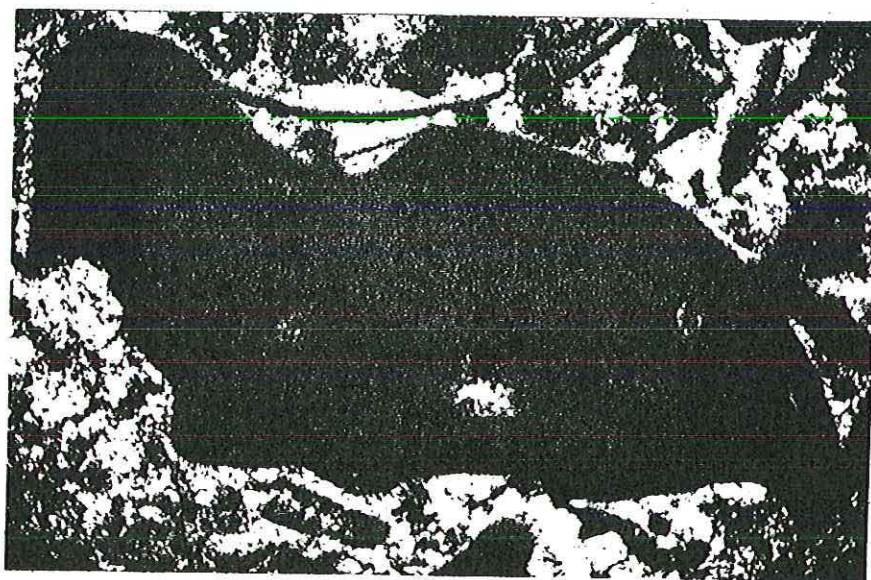
B

Figure 12. Intraclastic Pelmatozoan Wackepackstone Lithotype.

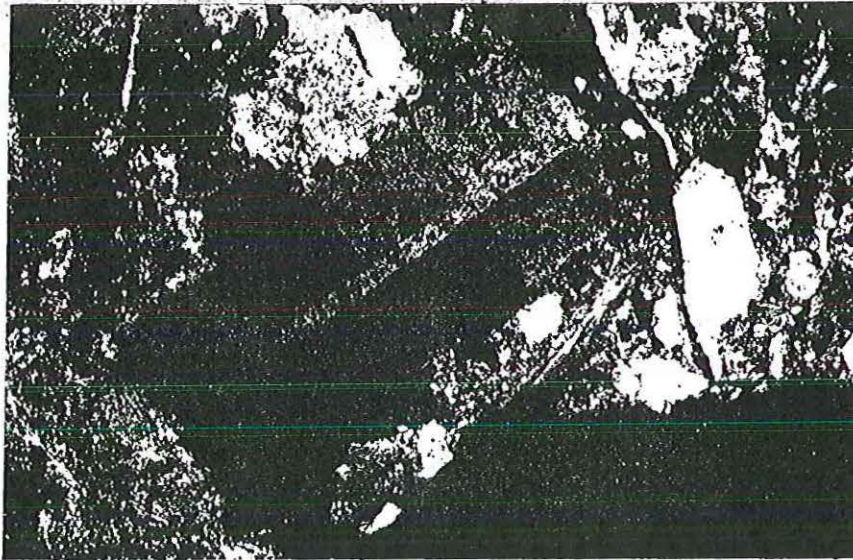
- A) Photomicrograph of skeletal hash (mostly brachiopods). Length of bar is 1 mm. Thin section no. 32-12566.
- B) Photomicrograph of an intraclast. Length of bar is 1 mm. Thin section no. 38-6979.
- C) Photomicrograph of pelmatozoan echinoderm columnals (a). Length of bar is 1 mm. Thin section no. 32-12565.
- D) Photomicrograph of a trilobite fragment (a). Length of bar is 1 mm. Thin section no. 32-12566.



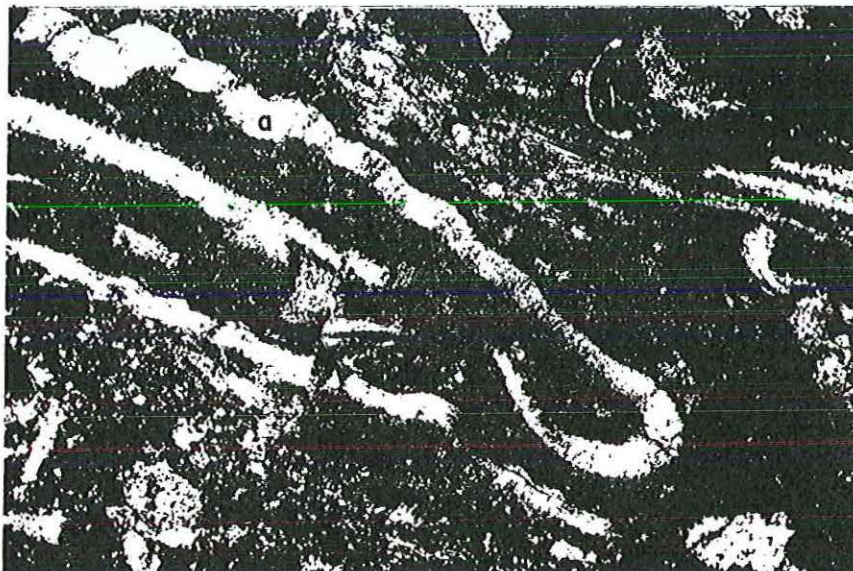
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remaining 25 percent of the allochems, in order of decreasing abundance, are brachiopods, trilobites (Fig. 12D), gastropods, ostracods, peloids, rare orthoconic cephalopods and green (codiacian?) algae. Sorting is generally poor. The matrix is brown or tan micrite.

Stromatolite and Cryptalgal Dololaminate

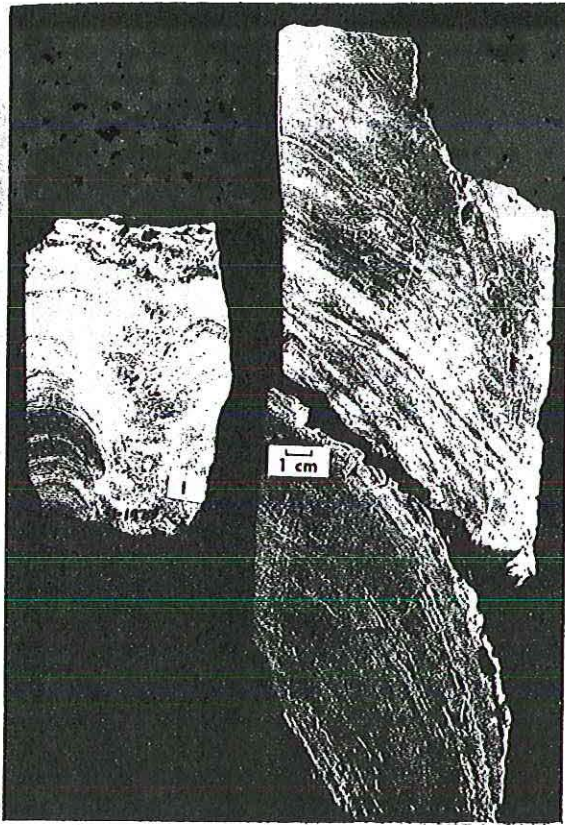
All rocks in the stromatolite and cryptalgal dololaminate lithotype are well laminated. Locally, the laminae are recognizably algal in origin and are termed stromatolites. In other laminates, an algal origin is less certain and these are termed cryptalgal.

Stromatolites are either columnar (Fig. 13A) or flat-lying (Fig. 13B). Columnar stromatolites range in height from 2.5 cm to 40 cm. Small pockets of peloids 125-177 microns in diameter flank and interfinger with the algal heads (Fig. 13C). Both columnar and flat-lying stromatolites are composed of closely spaced (0.1-1 mm) 1-2 micron thick laminae which are separated by mudstone, and may contain peloids 125-177 microns in diameter (Fig. 13C). Delicate, anastomosing tubes 1-2 microns in diameter are common in the flat-lying stromatolites and may represent algal filaments. Some flat-lying stromatolites are associated with evaporitic lithotypes and contain small (1 mm in length) celestite crystals (Fig. 13D) (B.C. Schreiber, personal communication, 1982) and anhydrite crystals.

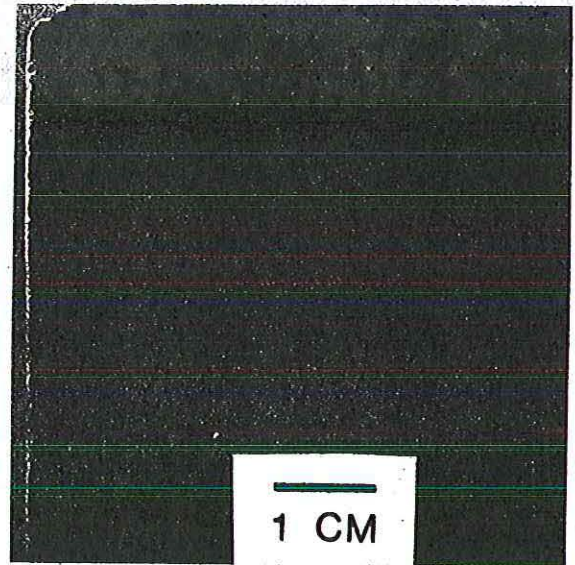
Cryptalgal dololaminates are composed of tan or pinkish-tan dolomitic mudstone which contains gray or yellow laminations. The laminations are commonly closely spaced (0.5 mm) but can be as much as 2 cm apart (Fig. 13E). Where well defined, the laminae

Figure 13. Stomatolite and Cryptalgal Dololaminate Lithotype.

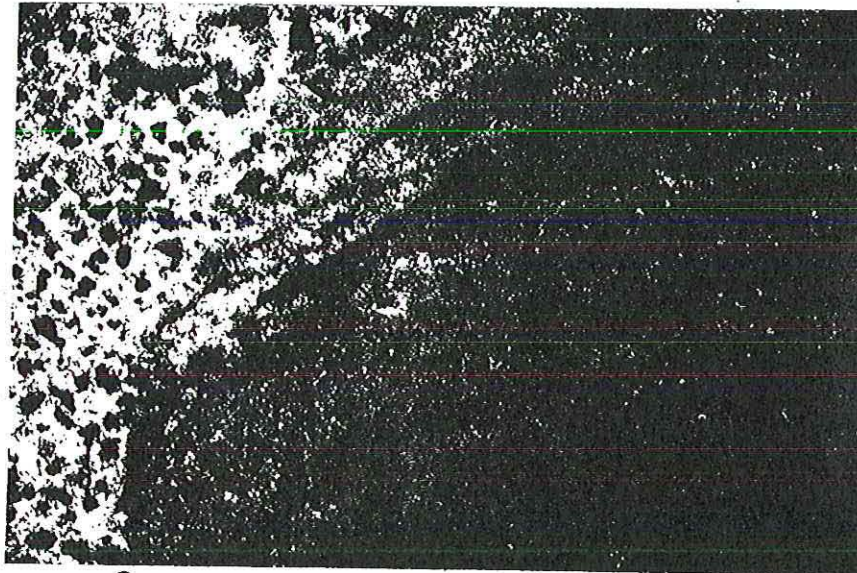
- A) Photograph of columnar stromatolites. Note fenestral porosity (a). Core no. 31-1970 on left, 27-2412 on right.
- B) Photograph of flat-lying stromatolites (a). Core no. 32-12573.
- C) Photomicrograph of columnar stromatolite (a) and adjacent peloids (b). Length of bar is 1 mm. Thin section no. 38-6953.
- D) Photomicrograph of celestite? crystals (a) in a stromatolite. Length of bar is 1 mm. Thin section no. 1606-13287.
- E) Photograph of cryptalgal dololaminte. Fine, gray laminae (a) may represent algal-bound surfaces. Darker laminae (b) are stylolites. Core no. 1606-13271.
- F) Photomicrograph of erosion surface on cryptalgal dololaminates (a). Note large rip-up clast (b). Core no. 1606-13278.



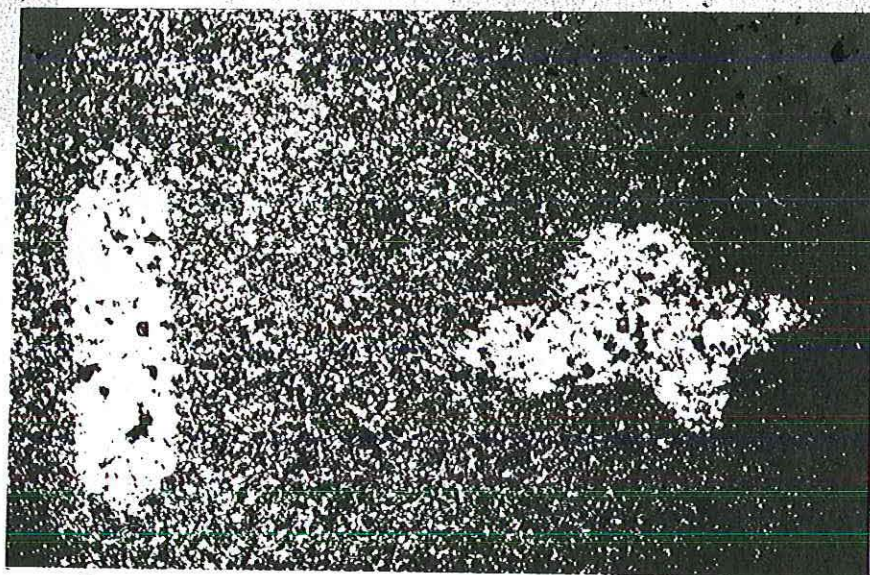
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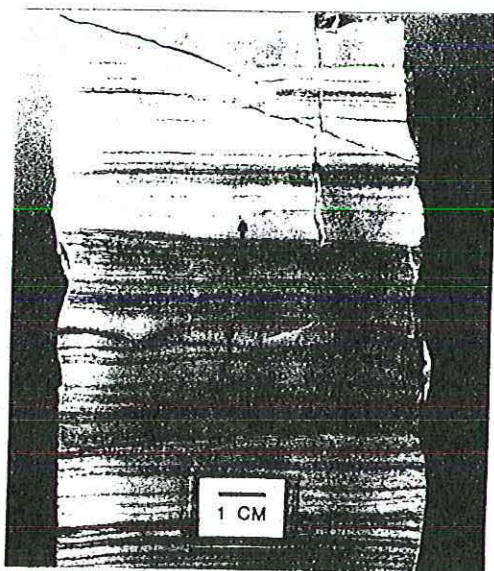
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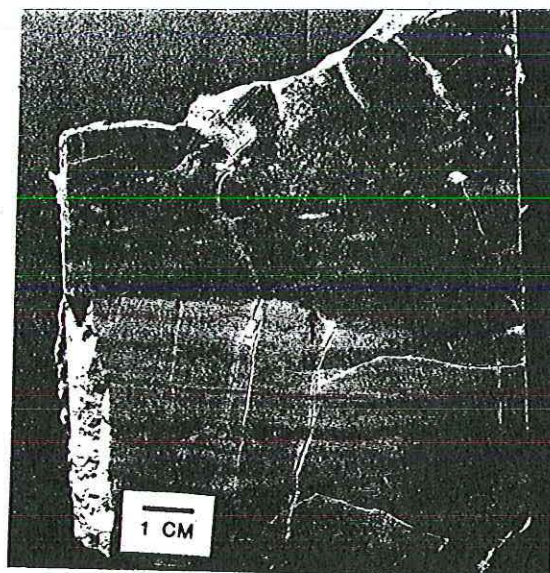
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are commonly planar, but may be contorted or truncated. Erosional surfaces truncate these laminations in places and are marked by large (up to 9 cm long) flat-pebble intraclasts in an intraclastic wackestone matrix (Fig. 13F). The intraclasts are composed of the same material as the underlying laminates.

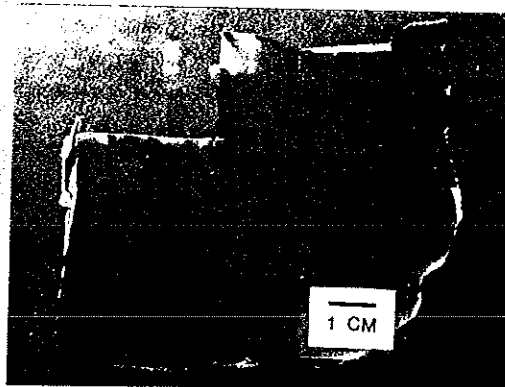
Anhydritic Dolomitic Mudstone

Anhydritic dolomitic mudstone is an uncommon but distinct lithotype and contains both nodular and laminar anhydrite. Nodular types contain nodular and thin-bedded mosaic anhydrite in a black to dark brown dolomitic mudstone matrix (Fig. 14A). The anhydrite nodules range from 3 mm to 4 cm in longest dimension and form either discrete layers about 1 cm thick with thin 1-2 mm laminae of dolomitic mudstone between them, or as "chicken-wire" anhydrite. The nodules are composed of small, lath-shaped anhydrite crystals 50-60 microns long which form felted masses that may contain wispy inclusions of dark brown, dolomitic mudstone (Fig. 14B).

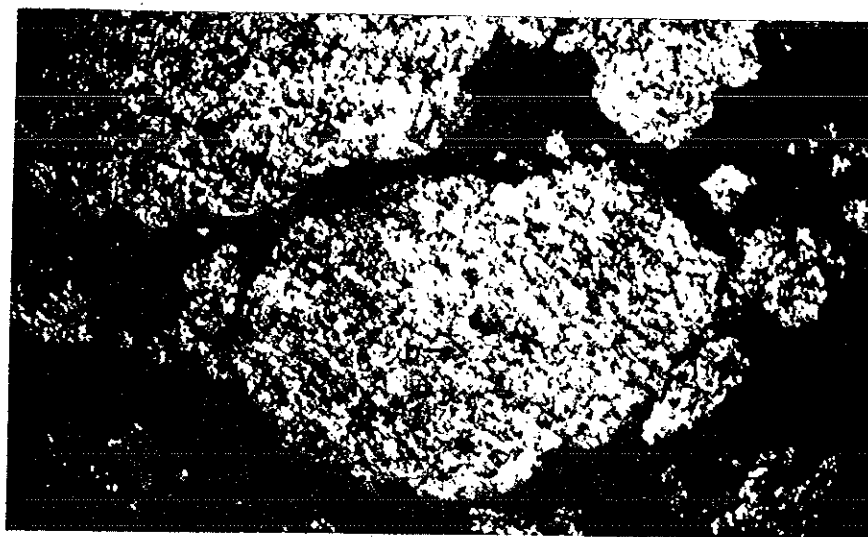
Laminar types of the anhydritic dolomitic mudstone lithotype contain even to slightly undulating laminae 0.5-2 mm thick composed of intercalated felted anhydrite crystals, 50-60 microns long, and brown to dark gray dolomitic mudstone (Fig. 14C). The contacts between the dolomitic mudstone and the anhydrite laminae are either sharp (Fig. 14D) or gradational (Fig. 14E). The anhydrite crystals within the anhydrite laminae have long axes that are roughly parallel to bedding. Small microclasts (88-125 microns in longest dimension) occur in the anhydrite laminae, and these microclasts are also elongate parallel to bedding (Fig. 14F).

Figure 14. Anhydritic Dolomitic Mudstone Lithotype.

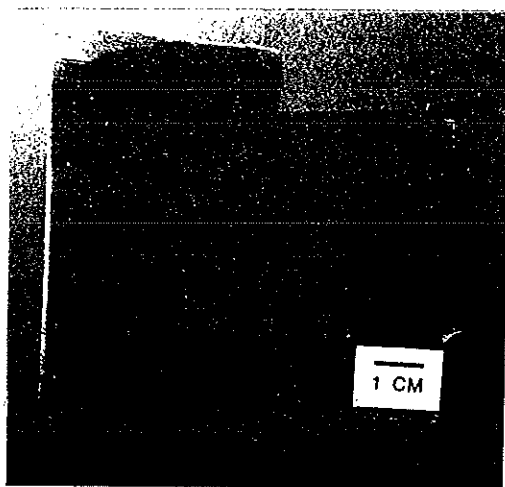
- A) Photograph of nodular anhydrite (a). Core no. 32-12570.
- B) Photomicrograph of anhydrite nodules (a). Note small, lath-shaped anhydrite crystals (b). Length of bar is 1 mm. Thin section no. 32-12570.
- C) Photograph of laminar anhydrite (a) and dolomitic mudstone (b). Core no. 32-12490.
- D) Photomicrograph of laminar anhydrite (a) and dolomitic mudstone (b) with sharp contacts (c). Length of bar is 1 mm. Thin section no. 32-12498.
- E) Photomicrograph of laminar anhydrite (a) and dolomitic mudstone (b) with gradational contacts (c). Length of bar is 1 mm. Thin section no. 32-12498.
- F) Photomicrograph of microclasts (a) in laminar anhydrite. Length of bar is 1 mm. Thin section no. 32-12490.



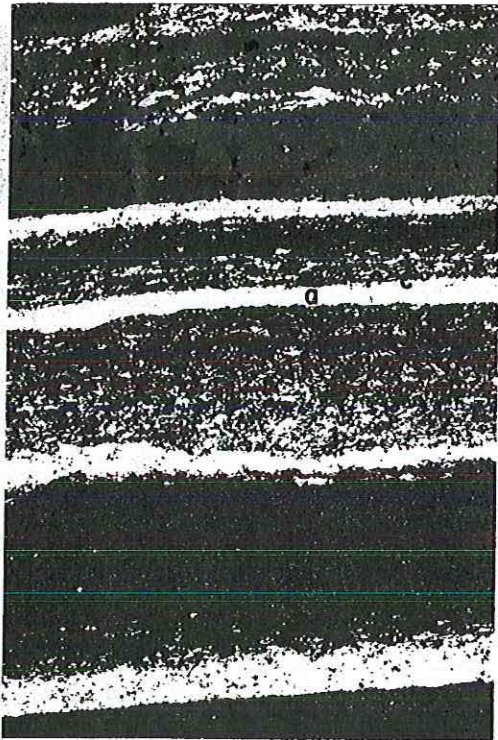
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Mudstone

Mudstone forms interlaminae, interbeds, or layers several feet thick in all other lithotypes. Most mudstone is tan, but brown and gray mudstone is also present. Some mudstone may contain up to 10 percent angular quartz silt. Burrows, which form anastomosing networks of mud-infilled tubes 1-2 mm in diameter, are found in mudstone but are not common. Where associated with evaporitic lithotypes, small 1 mm-long, lath-shaped, anhydrite crystals are distributed throughout the mudstone (about 5 percent of total volume).

Ferruginous Dolostone and Limestone

and Brecciated Dolostone

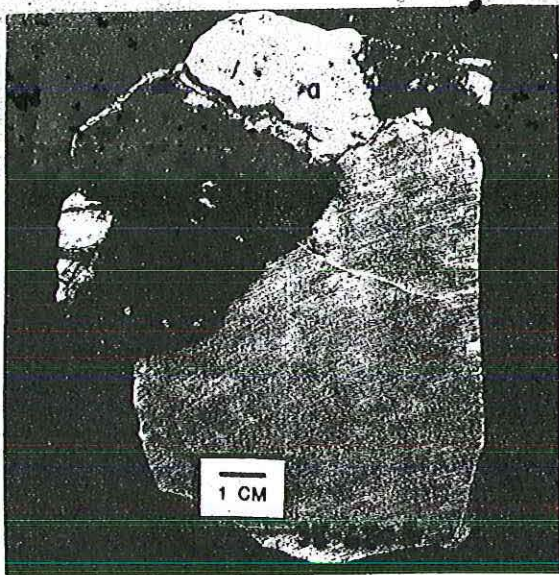
Thick sections of rock in the Interlake at the contact with the Ashern Formation, and intraformationally as well, have been so altered that their original textures have been totally destroyed. Therefore, the carbonate rock classification used thus far (Dunham, 1962) is not applicable to these rocks, and they are here referred to as ferruginous dolostone and limestone and brecciated dolostone.

Ferruginous Dolostone and Limestone

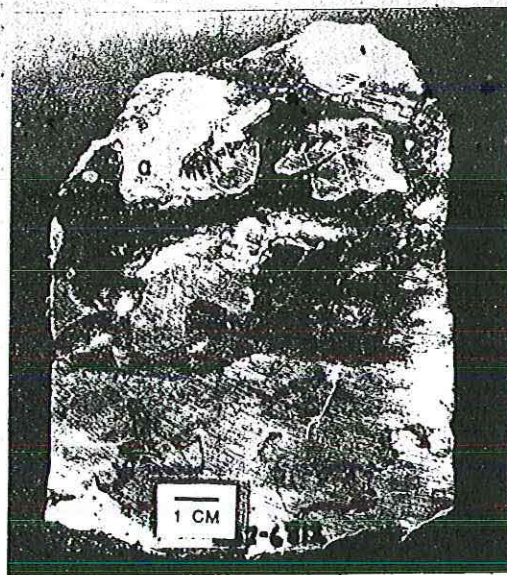
Ferruginous dolostone and limestone consist of brecciated dolostone in a red, earthy matrix (Fig. 15A and 15B). The dolostone clasts are angular, range in size from 2 cm to 25 cm in longest dimension and are composed of crystalline dolomite. The individual dolomite crystals are equant and average 0.5-1 mm in length. The matrix can be composed of fine-grained iron oxides and calcite

Figure 15. Ferruginous Dolostone and Limestone Lithotype.

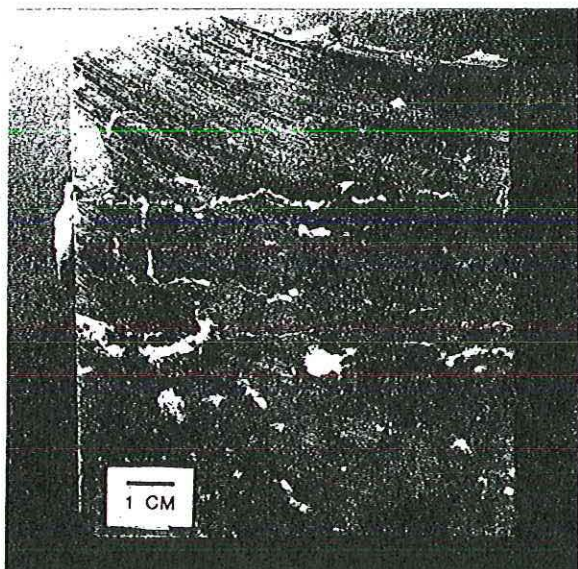
- A) Photograph of large clasts of dolostone (a) in ferruginous matrix (b). Core no. 38-6805.
- B) Photograph of angular clasts of dolostone (a) "floating" in ferruginous matrix (b). Core no. 38-6812.
- C) Photograph of rock completely altered to ferruginous material. Core no. 38-6758.
- D) Photomicrograph of core in 15C. Note ferruginous matrix (a) and grains (b). Length of bar is 1 mm. Thin section no. 38-6758.
- E) Photograph of ferruginous ooids (a) and pisolites (b). Core no. 38-6704.
- F) Photomicrograph of opaque ferruginous ooids (a). Length of bar is 1 mm. Thin section no. 505-54.
- G) Photomicrograph of slightly translucent ferruginous ooids (a). Note ostracods (b) with geopetal infill (c). Length of bar is 1 mm. Thin section no. 505-53G.
- H) Photomicrograph of ferruginous pisolite composed of cross-cutting fibrous bundles (a). Length of bar is 1 mm. Thin section no. 38-6805.



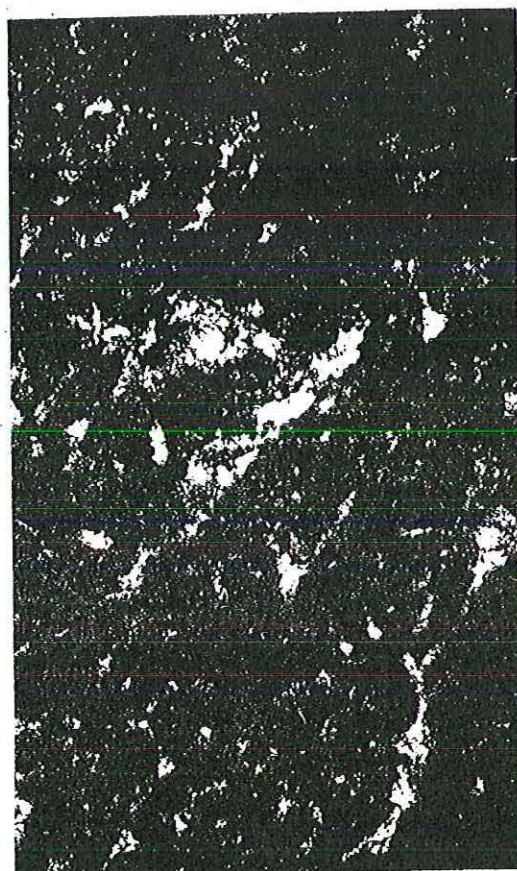
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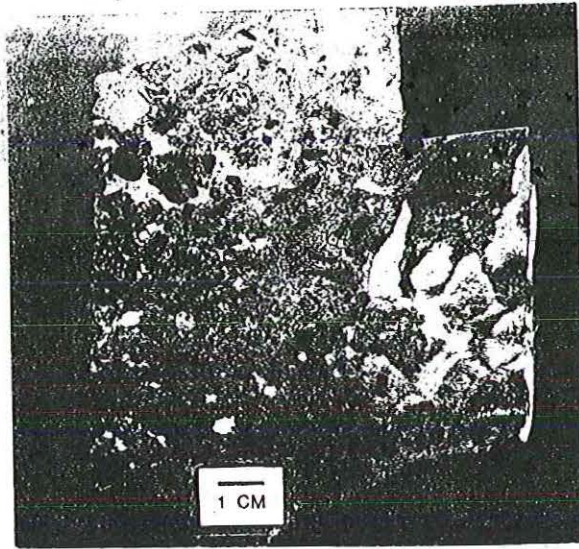
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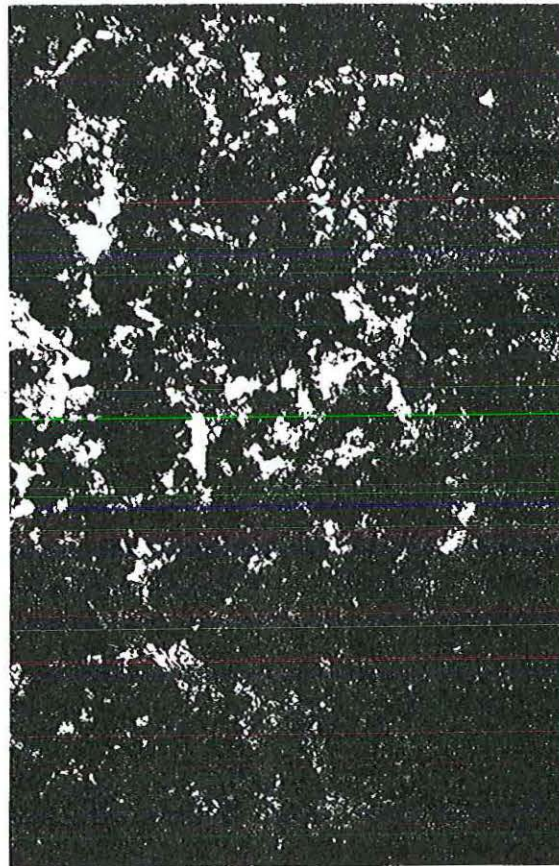
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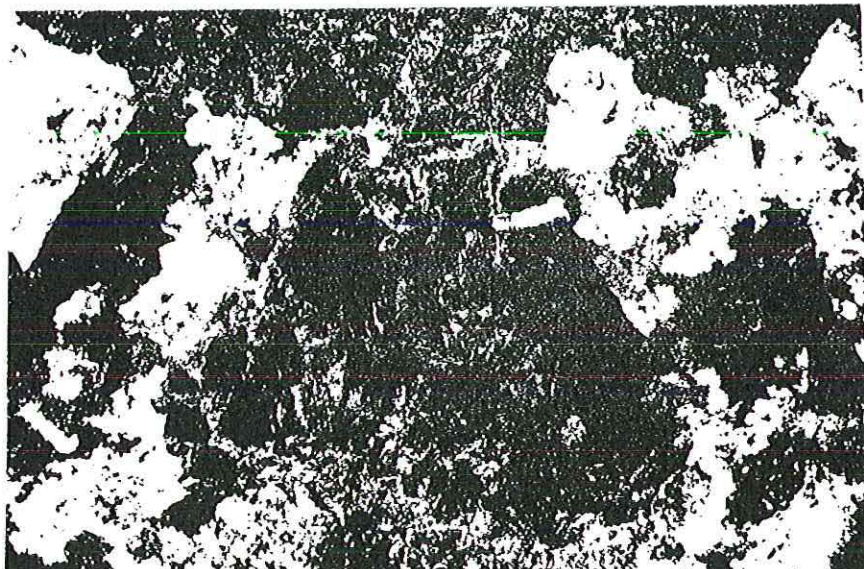
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(Fig. 15C and 15D) or consist of irregularly shaped ferruginous ooids and pisolites which range from 0.25 - 4 mm in diameter (Fig. 15E). The ooids and pisolites are generally opaque to slightly translucent (Fig. 15F and 15G), red, and internally featureless. However the larger pisolites, which are extremely irregular in shape, may have internal laminae which occur in cross-cutting bundles (Fig. 15H) or are composed of aggregates of smaller (125-177 micron), opaque, iron oxide clots.

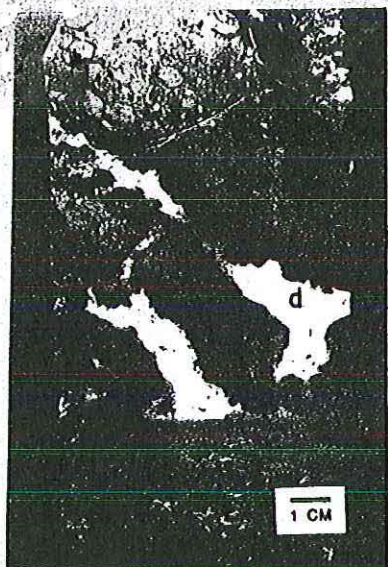
Zones of ferruginous dolostone can be up to 30 meters thick and occur intraformationally as well as at the contact with the Ashern Formation. Where intraformational, the upper portions of these zones are reworked forming clasts in the overlying Interlake carbonates.

Brecciated Dolostone

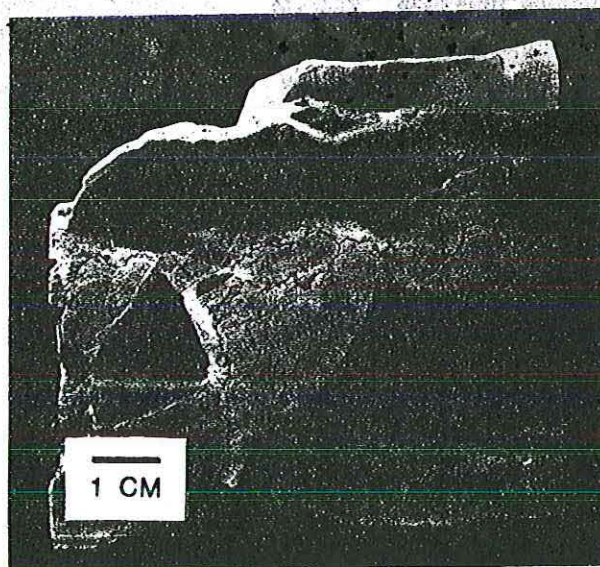
Brecciated dolostone is characteristically dark gray and is composed of angular clasts of dolostone ranging from 1 cm to 16 cm in longest dimension (Fig. 16A and 16B). These clasts commonly contain between 5 and 10 percent dark gray, opaque, peloids, 250-350 microns in diameter, floating in a lighter gray, dolomitic, mudstone matrix (Fig. 16C). Some peloids are surrounded by a thin rind (10-20 microns thick) of very fine crystalline dolomite. Microbrecciation (Fig. 16D) and laminar calcite coatings which are brecciated (Fig. 16E) are distinct features in brecciated dolostones. Locally, 1-2 micron-thick laminar coatings form concentrically, creating pisolite-sized spherulites (Fig. 16F). Brecciated dolostone forms the top 7 to 9 meters of the Interlake Formation in

Figure 16. Brecciated Dolostone Lithotype.

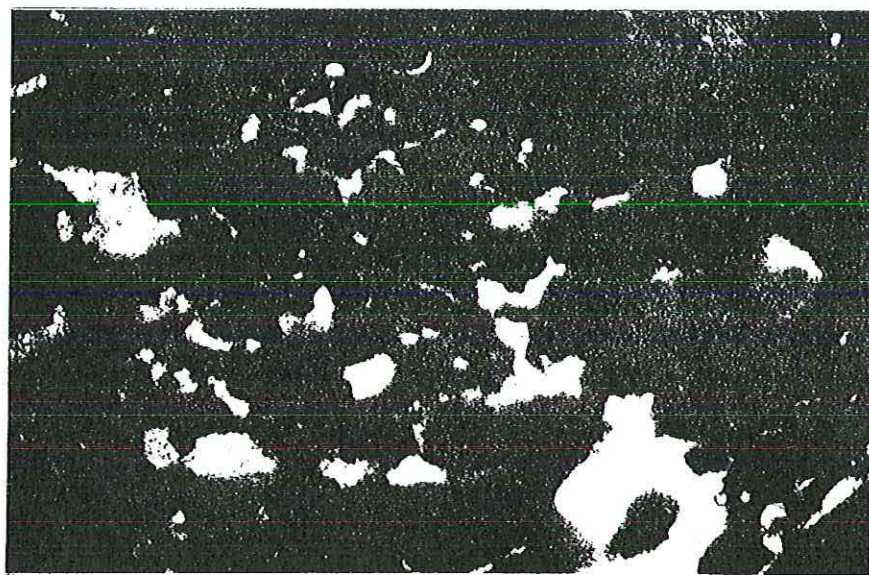
- A) Photograph of brecciated dolostone showing clasts (a), gravity cement (b), geopetal infill (c), and saddle dolomite cement (d). Core no. 32-11574.
- B) Photograph of brecciated dolostone showing angular clasts (a). Core no. 470-11037.
- C) Photomicrograph of core in 16A. Note fine-grained matrix (a) and opaque grains (b). Length of bar is 1 mm. Thin section no. 32-11574A.
- D) Photomicrograph of microbrecciated horizon. Length of bar is 1 mm. Thin section no. 32-11569½.
- E) Photomicrograph of brecciated laminar coatings (a). Length of bar is 1 mm. Thin section no. 505-53G.
- F) Photomicrograph of pisolite-sized spherulite. Length of bar is 1 mm. Thin section no. 32-11578.



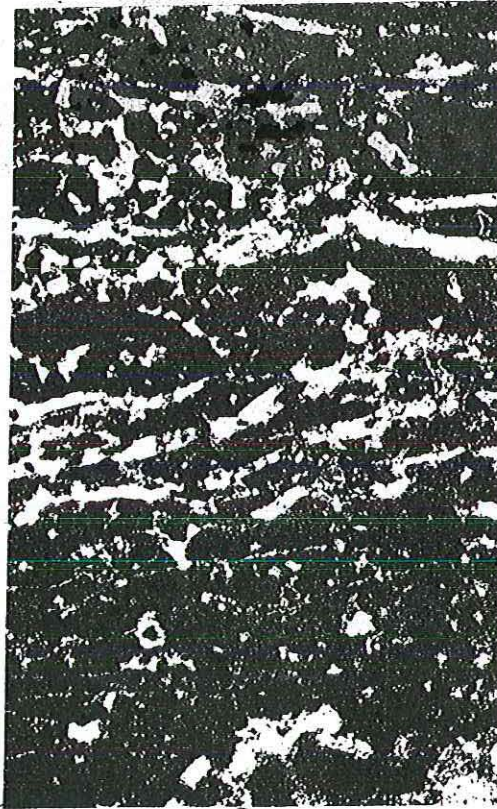
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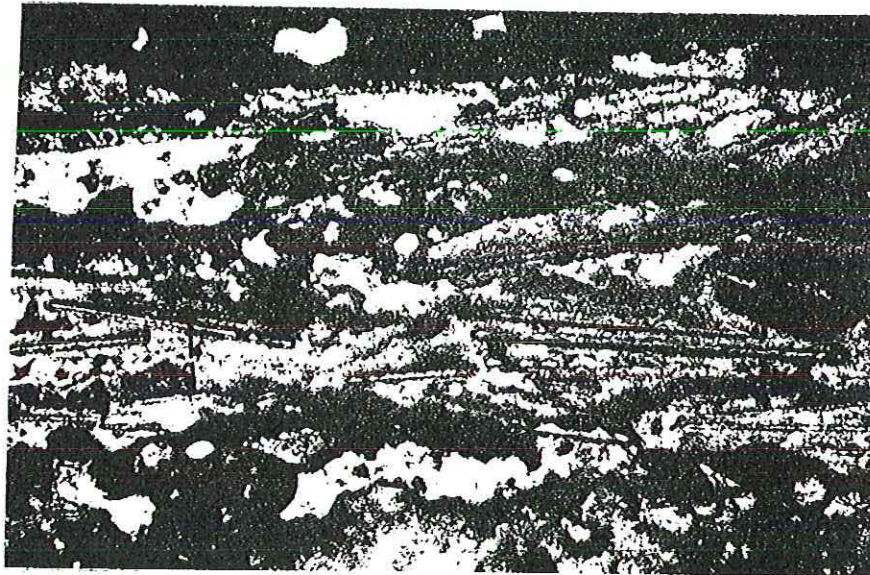
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some cores, but it can also occur at other levels within the Interlake.

DIAGENETIC FEATURES

Introduction

Rocks in the Interlake Formation are dominated by four types of diagenetic features. These are: 1) dolomite (replacement); 2) porosity; 3) cement (pore-filling); and 4) severe alteration and brecciation. Replacement by quartz is a minor diagenetic feature also observed in Interlake rocks. Several of the preceding lithotypes were defined on the basis of diagenetic features; for example, fenestral peloidal wackestone, ferruginous dolostone and limestone and brecciated dolostone. These features will be included in the following descriptions, but will not be discussed with the same detail as in the preceding text.

Dolomite

Dolomitization is pervasive throughout most of the Interlake Formation. The type and degree of dolomitization that occurred differs among the various lithotypes and locally within them.

Microcrystalline dolomite occurs as a matrix and as the dominant component of peloids and intraclasts in the peloidal quartz silt packstone and fenestral peloidal wackestone lithotypes (Fig. 17A). Gastropod shells in these lithotypes may be composed of microcrystalline dolomite, but usually are composed of medium-grained dolomite crystals (see Fig. 8D). Microcrystalline dolomite also occurs as a matrix and as laminations in the anhydritic

dolomitic mudstone lithotype and in the stromatolite and cryptalgal dololaminate lithotypes.

Small, 62-88 micron, dolomite rhombs occur in the trilobite mudstone and in the intraclastic pelmatozoan wackestone lithotypes. These dolomite rhombs are euhedral and occur floating in the micrite matrix of these lithotypes.

In the ooid grainstone lithotype, dolomite occurs as small patches within the ooids, partially destroying their original fabric (Fig. 17B). The dolomite in these patches is very fine grained.

Coarse-grained dolomite rhombs occur in the pelmatozoan anthozoan wackestone lithotype. The rhombs are large (1 mm in cross section) and replace both matrix (Fig. 17C) and allochems (Fig. 17D). These dolomite rhombs are zoned with cloudy interiors and clean edges. Locally rocks in this lithotype are completely dolomitized (Fig. 17E).

Dolomite rhombs are also found adjacent to stylolites in several lithotypes (Fig. 17F). The dolomite can occur as small, densely packed rhombs within microstylolite swarms (Fig. 17G and 17H), as small rhombs concentrated in a thin zone on one side of a stylolite (Fig. 17I), or as large rhombs which pervasively replace the host rock on one side of a stylolite and are present in small amounts on the other side of the stylolite (Fig. 17J). This dolomitization is so complete in portions of the stromatolite and cryptalgal dololaminate lithofacies that the rock is composed of a mosaic of euhedral to subhedral dolomite crystals (Fig. 17K). Completely dolomitized rocks in the pelmatozoan anthozoan

Figure 17. Examples of replacement dolomite in the Interlake Formation.

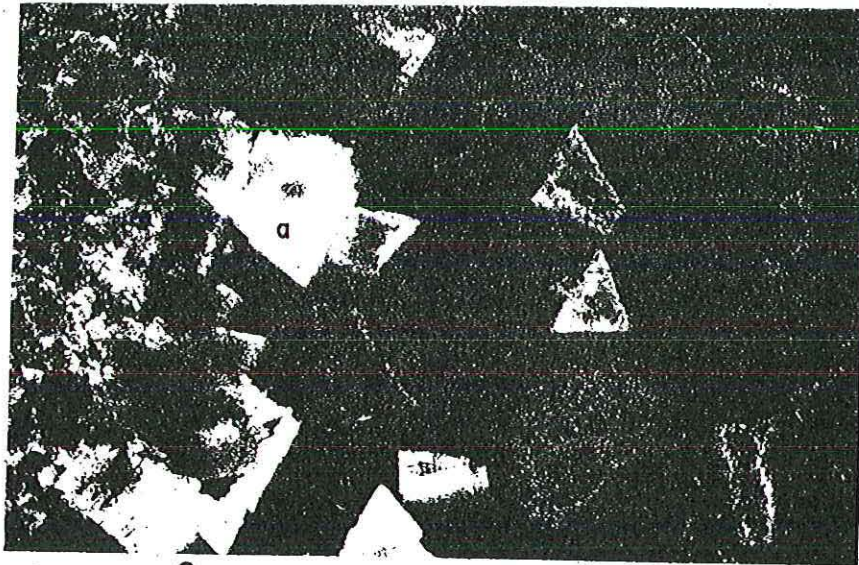
- A) Photomicrograph of dolomitized peloids (a) and dolomitic mudstone (b). Length of bar is 1 mm. Thin section no. 32-11666.
- B) Photomicrograph of partially dolomitized ooids. Dolomite forms fine-grained patches (a). Length of bar is 1 mm. Thin section no. 31-1951A.
- C) Photomicrograph of large dolomite rhombs (a) replacing mudstone matrix (b). Note pelmatozoan echinoderm fragment (c). Length of bar is 1 mm. Thin section no. 38-6877.
- D) Photomicrograph of large dolomite rhombs (a) replacing a rugose coral (b). Length of bar is 1 mm. Thin section no. 38-6877.
- E) Photomicrograph of totally dolomitized tabulate coral (a). Length of bar is 1 mm. Thin section no. 1606-13202.
- F) Photograph of dolomite rhombs (a) concentrated adjacent to stylolites (b). Core no. 38-6887.
- G) Photomicrograph of dolomite rhombs (a) in a microstylolite swarm (b). Length of bar is 1 mm. Thin section no. 32-1256?
- H) Photomicrograph of dolomite rhombs (a) in a microstylolite swarm (b). Length of bar is 1 mm. Thin section no. 505-53D.
- I) Photomicrograph of dolomite rhombs (a) concentrated in a thin zone along one side of a stylolite (b). Length of bar is 1 mm. Thin section no. 505-62.
- J) Photomicrograph of large dolomite rhombs (a) totally replacing host rock on one side of a stylolite (b). Length of bar is 1 mm. Thin section no. 38-6979.
- K) Photomicrograph of totally dolomitized rock composed of a mosaic of euhedral and anhedral dolomite crystals. Length of bar is 1 mm. Thin section no. 1601-13273.
- L) Photograph of nodular texture in completely dolomitized portions of the pelmatozoan anthozoan wackestone lithotype. Core no. 27-2397.



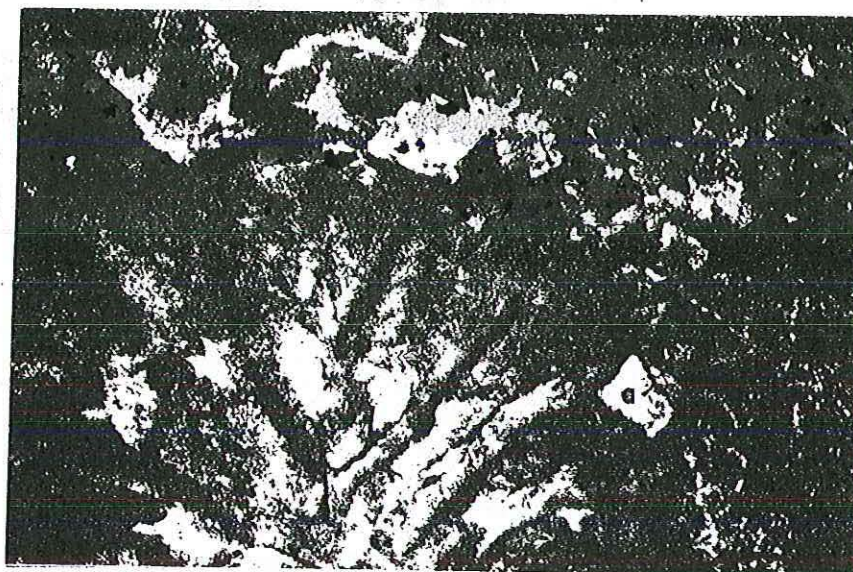
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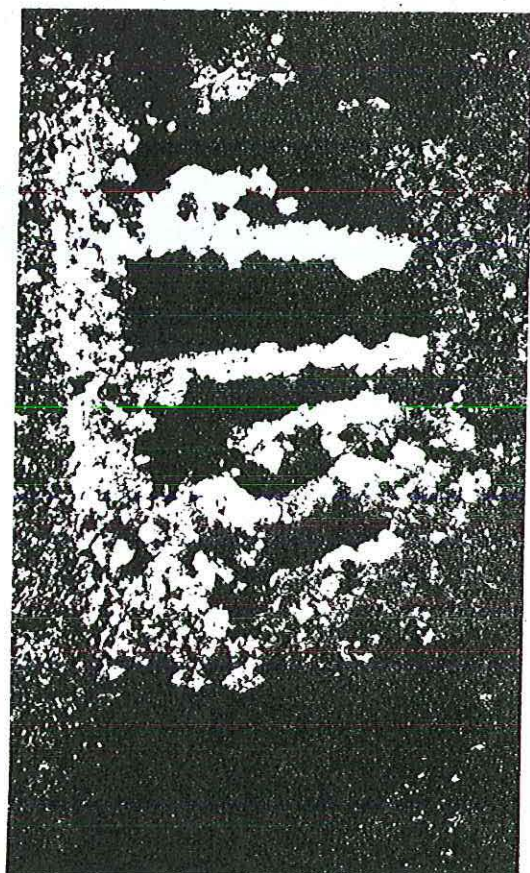
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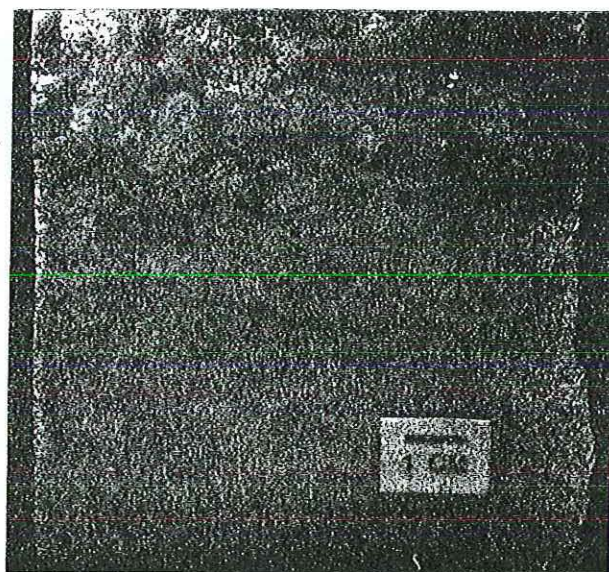
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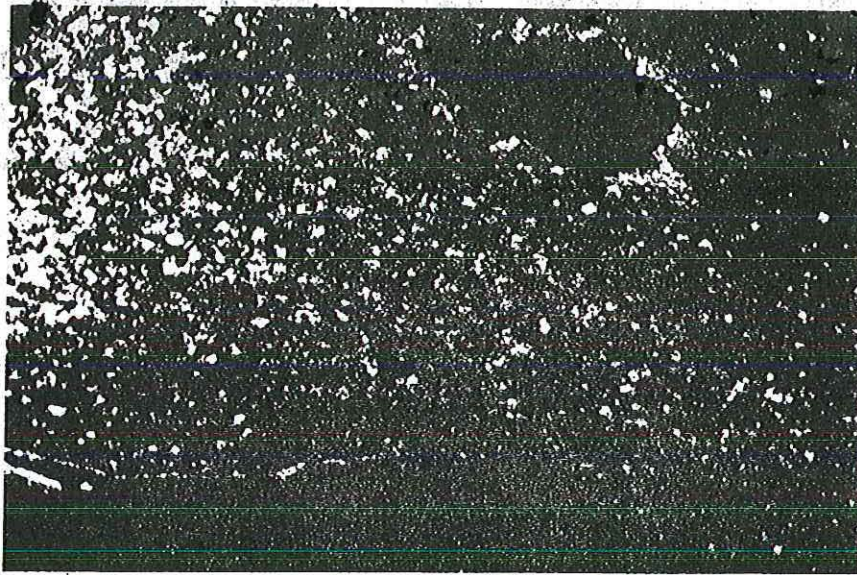
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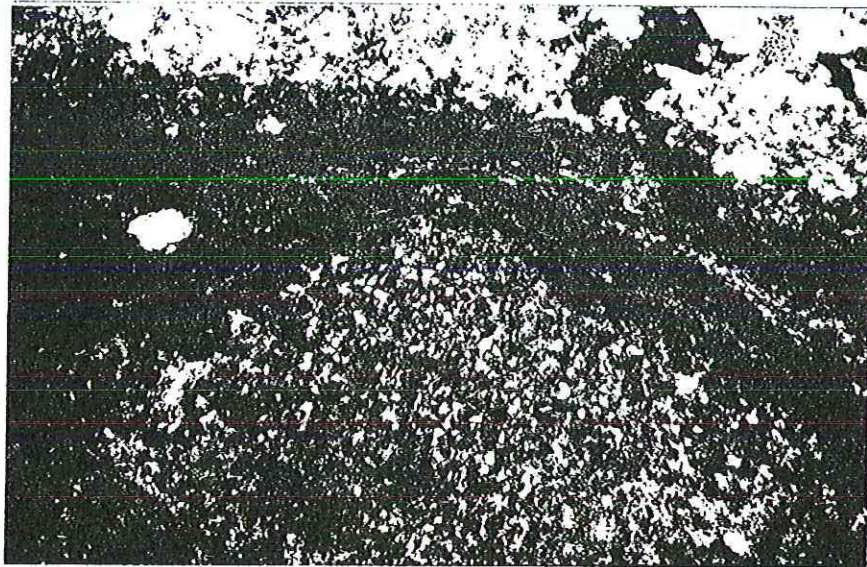
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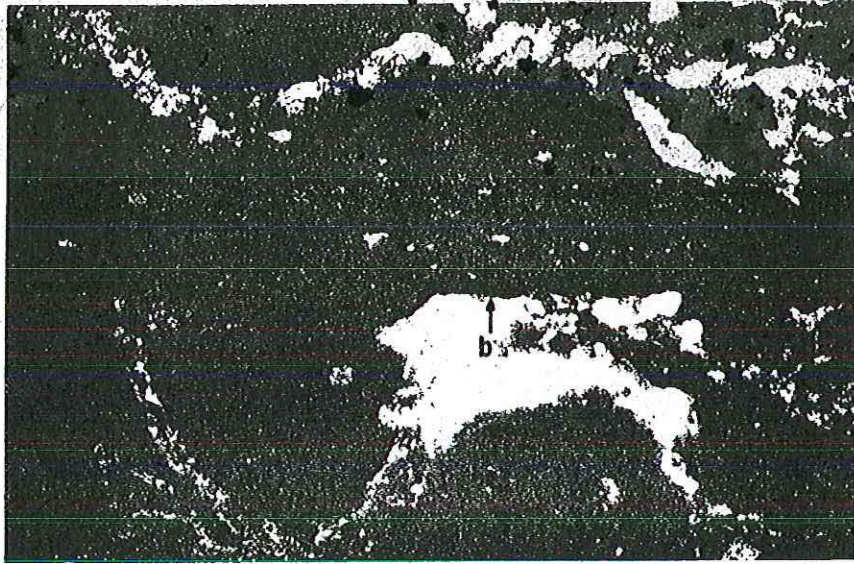
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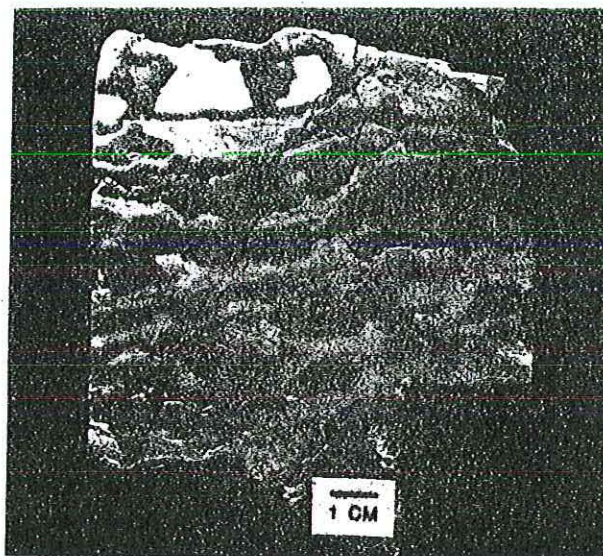


H





K



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wackestone lithotype locally display a nodular texture (Fig. 17L). The dolomite rhombs tend to be finer grained within the nodules and coarser grained surrounding the nodules.

Porosity

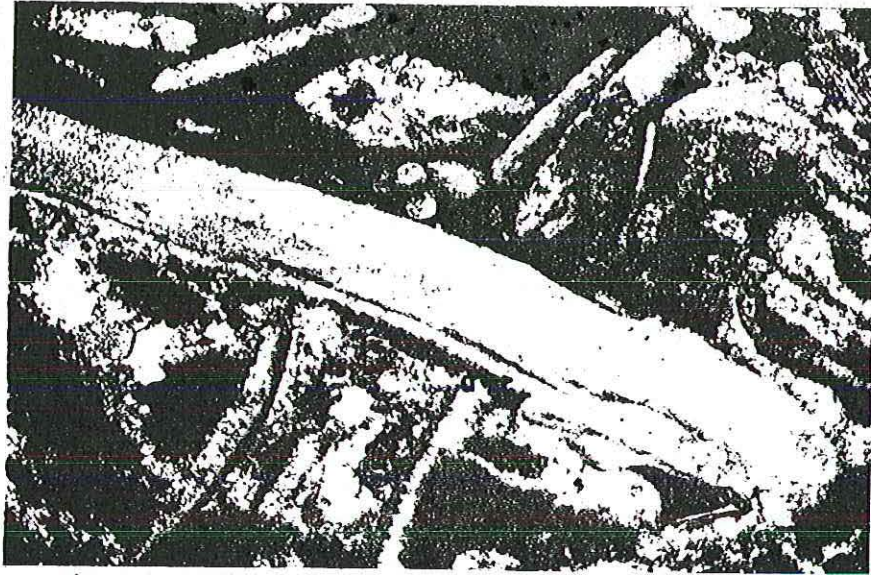
Several types of porosity can be found in the Interlake Formation. The amount and type of porosity present varies considerably between lithotypes. Skeletal intraparticle and shelter porosity are present in the pelmatozoan anthozoan wackestone lithotype, but are not common (Fig. 18A). Interparticle porosity occurs in the ooid grainstone (Fig. 18B) and peloidal quartz silt packstone lithotypes. This porosity type is also uncommon.

Fenestral porosity is abundant in the fenestral peloidal wackestone lithotype and occurs in lesser amounts in the stromatolite and cryptalgal dololaminate lithotype. Fenestral porosity is solution-enhanced, locally creating extremely permeable horizons (Fig. 18C). Moldic porosity, after gastropods, is found in the peloidal quartz silt wackestone lithotype, after brachiopods in the pelmatozoan anthozoan wackestone lithotype, and after ooids in the ooid grainstone lithotype.

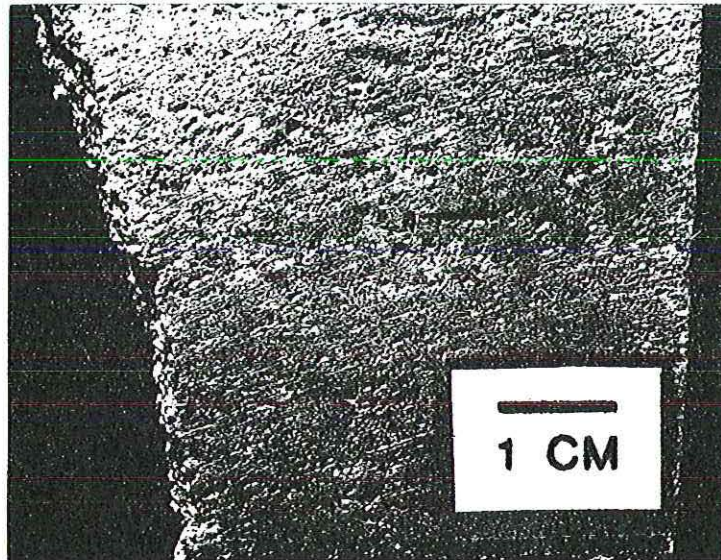
Vugular and pinpoint porosities are the most abundant porosity types in the Interlake. They are most common in the brecciated dolostone and ferruginous dolostone and limestone lithotypes, and are present in lesser amounts in the pelmatozoan anthozoan lithotype. Individual vugs can be up to 8 cm in longest dimension. Most vugular porosity is smaller, averaging 1 cm in longest dimension (Fig. 18D).

Figure 18. Examples of porosity types in the Interlake Formation.

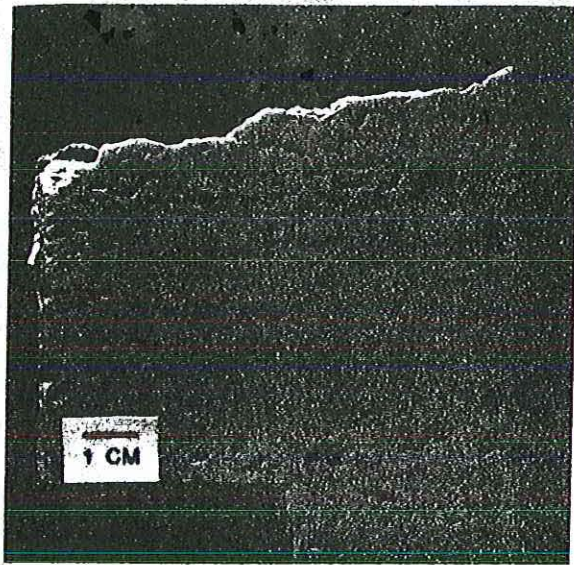
- A) Photomicrograph of shelter porosity (a). Length of bar is 1 mm. Thin section no. 38-6976½.
- B) Photograph of interparticle porosity (a) in ooid grainstone. Core no. 31-1951B.
- C) Photograph of fenestral porosity (a) (solution enhanced) in fenestral peloidal wackestone. Core no. 38-7613.
- D) Photograph of vugular porosity (a). Core no. 548-179.
- E) Photomicrograph of intercrystalline porosity (a). Note pelmatozoan echinoderm columnal (b) and dolomite rhombs (c). Length of bar is 1 mm.



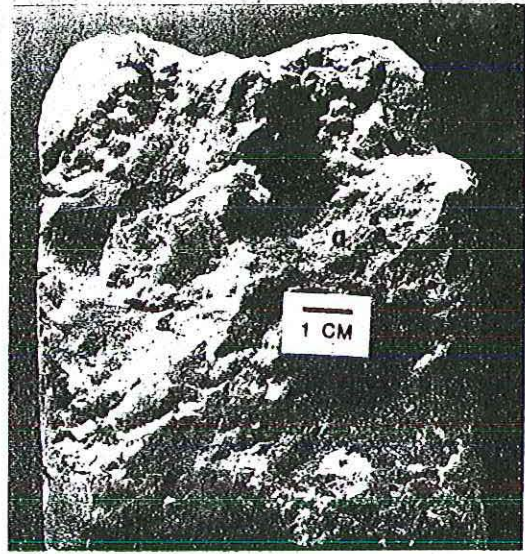
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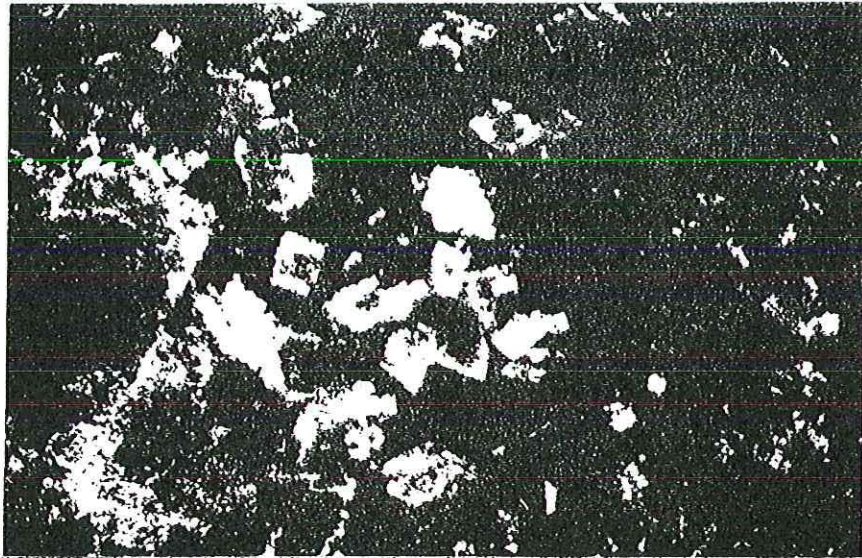
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Intercrystalline porosity is present in completely dolomitized rocks (Fig. 18E) and is distinct in completely dolomitized stromatoporoids and tabulate corals, enabling identification of completely replaced specimens.

Fracture porosity is also found in the Interlake, but is difficult to describe or quantify due to severe breakage of the core subsequent to extraction.

Cement

Most of the porosity in the Interlake is occluded by cement. The definition of cement used in this description is that of Bathurst (1976, p. 416), that is, "all passively precipitated space-filling carbonate crystals which grow attached to a free surface". This definition can also be applied to other minerals, such as anhydrite. The distribution and type of cement varies between lithotypes and is often specific to a porosity type.

In the ooid grainstone lithotype interparticle porosity is partially occluded by well-developed isopachous cement which forms rinds 50 microns thick on allochems (Fig. 19A). This cement displays a well-developed, radial, fibrous habit with individual crystal fibers growing perpendicular to the surface of the allochems. Bladed calcite is found lining fenestral porosity in the fenestral peloidal wackestone lithotype (Fig. 19B). Geopetal sediment often rests on top of these bladed cements (see Fig. 9E).

Pendant or gravity cement commonly occludes vugular porosity in the brecciated dolostone and the ferruginous dolostone and limestone lithotypes. In brecciated dolostone, pendant cement is

found growing from the roof of vugs (Fig. 19C) or from the bottom of clasts (Fig. 19D). The cement consists of fine laminations of dolomite (although some may be calcite, Fig. 19E) and may form individual "microstalactites" up to 3-4 mm long (Fig. 19F). In ferruginous dolostone and limestone, pendant cement consists of intercalated equant calcite crystals and iron oxide laminae (Fig. 19G), and is found growing from the roof of vugs. Some larger ferruginous pisolites have a fibrous calcite and iron oxide rind 0.5 mm thick. These rinds tend to become thicker along the bottom of the pisolites, indicating that the material of the rind may also include gravity cement (Fig. 19H).

Equant calcite is the most common type of cement in the Interlake Formation. It is usually equant and forms interlocking mosaics of crystals 177-350 microns in largest dimension (Fig. 19I). Equant calcite is the predominant cement occluding fenestral porosity in the fenestral peloidal wackestone lithotype and interparticle porosity in the peloidal quartz silt wackestone lithotype.

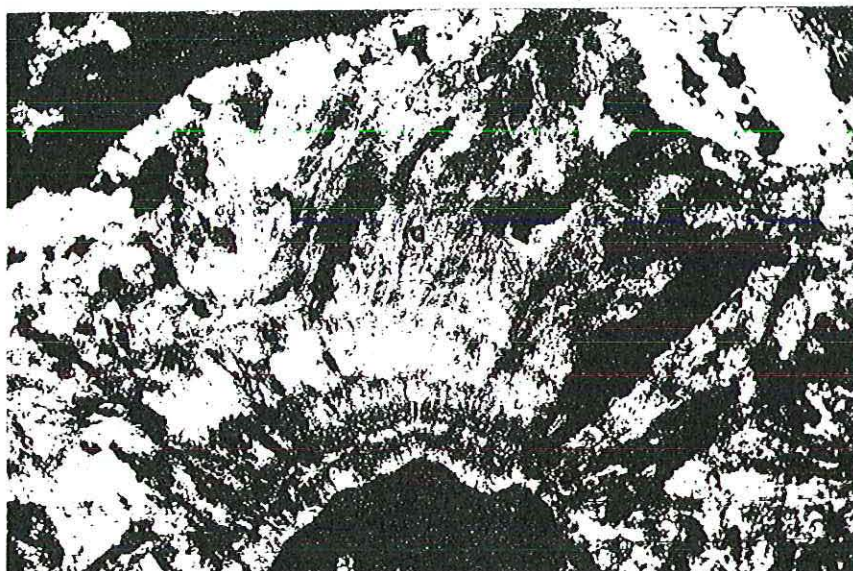
Equant dolomite cement, uncommon in the Interlake, is usually found lining vugs (Fig. 19J). Locally, equant dolomite grades into baroque or saddle dolomite (Fig. 19K). Saddle dolomite has a warped crystal lattice which is evident from the curved nature of the crystal cleavage and sweeping extinction in cross-polarized light (Radke and Mathis, 1980, p. 1149). In the Interlake Formation, saddle dolomite is very coarse grained; individual equant to slightly elongate crystals ranged between 2 and 5 mm in length. In the Interlake Formation, it is restricted to core from the deepest parts

Figure 19. Examples of cement in the Interlake Formation.

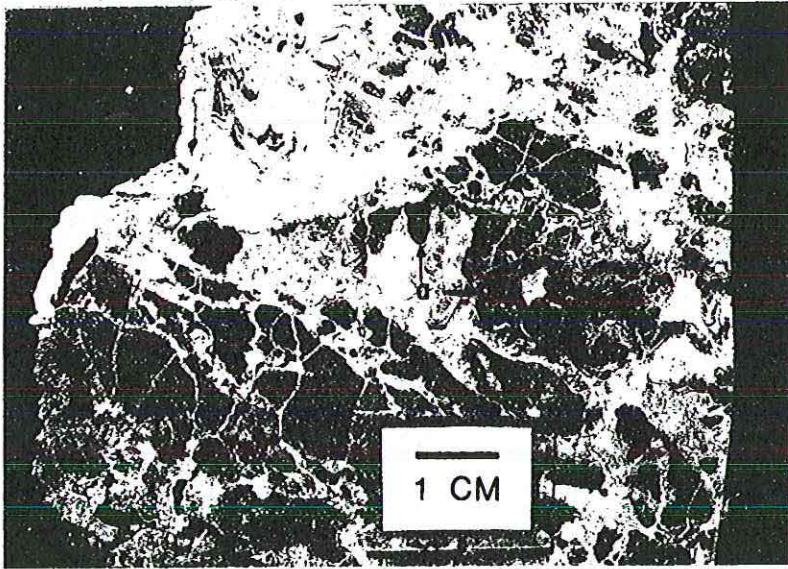
- A) Photomicrograph of fibrous isopachous cement (a) in ooid grainstone. Length of bar is 1 mm. Thin section no. 31-1972B.
- B) Photomicrograph of bladed calcite cement (a) in fenestral porosity. Length of bar is 1 mm. Thin section no. 147-12268.
- C) Photograph of pendant cement (a) in vug in brecciated dolostone. Core no. 25-11654.
- D) Photograph of pendant cement (a) growing from clasts (b) in brecciated dolostone. Core no. 548-10930.
- E) Photomicrograph of pendant cement composed of intercalated calcite (a) and dolomite (b) laminae. Length of bar is 1 mm. Thin section no. 147-12265½.
- F) Photomicrograph of "microstalactites" (a). Length of bar is 1 mm. Thin section no. 25-11637.
- G) Photomicrograph of pendant cement (a) in ferruginous dolostone and limestone. Length of bar is 1 mm. Thin section no. 38-6813.
- H) Photomicrograph of fibrous pendant cement (a) on a ferruginous pisolite (b). Length of bar is 1 mm. Thin section no. 38-6805.
- I) Photomicrograph of equant calcite cement (a) in fenestral porosity. Length of bar is 1 mm. Thin section no. 147-12257½.
- J) Photograph of euhedral dolomite cement (a) in a vug. Core no. 38-6918.
- K) Photomicrograph of saddle dolomite (a). Note curved extinction band (b). Length of bar is 1 mm. Thin section no. 32-11578.
- L) Photograph of anhydrite cement (a) in a fracture. Core no. 207-4721.
- M) Photomicrograph of anhydrite cement (a) in moldic porosity. Length of bar is 1 mm. Thin section no. 32-11581.



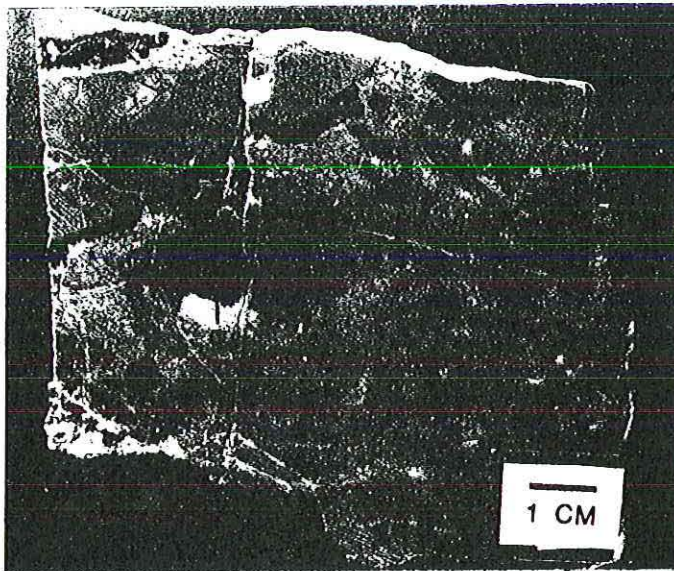
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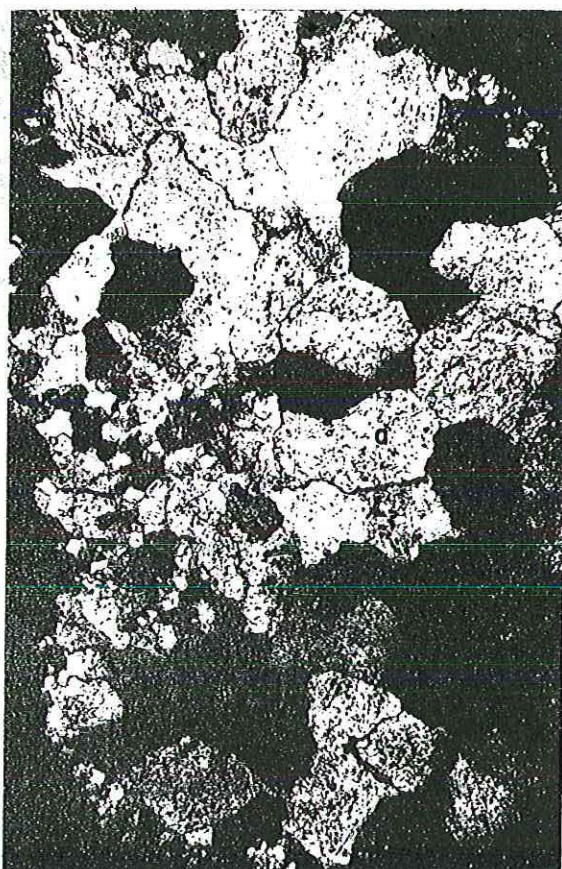
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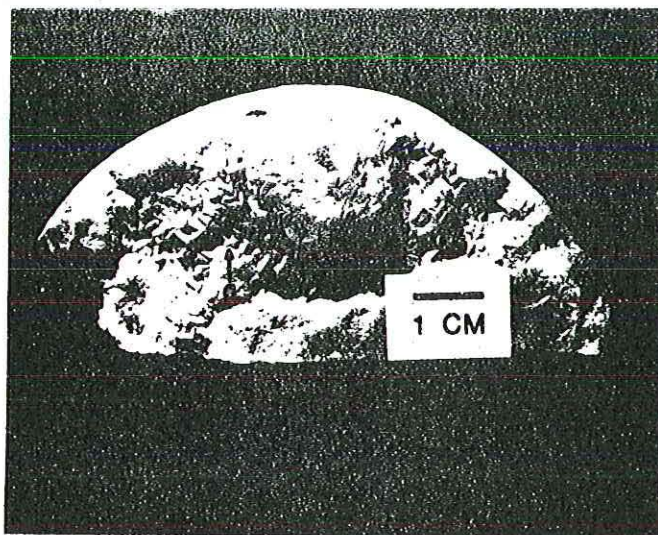
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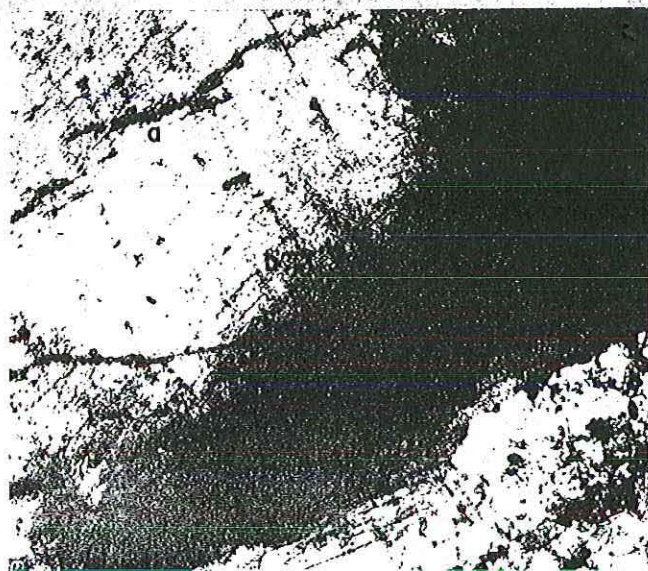
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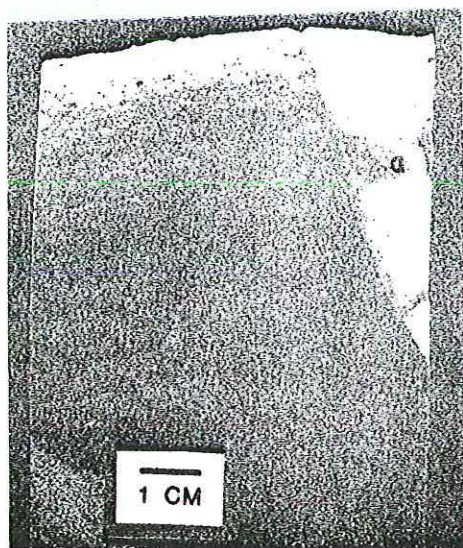
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of the Interlake in western North Dakota.

Halite and anhydrite cements are present in small amounts. Halite occludes vugular porosity in brecciated dolostone, and anhydrite occludes both fracture (Fig. 19L) and moldic (Fig. 19M) porosity.

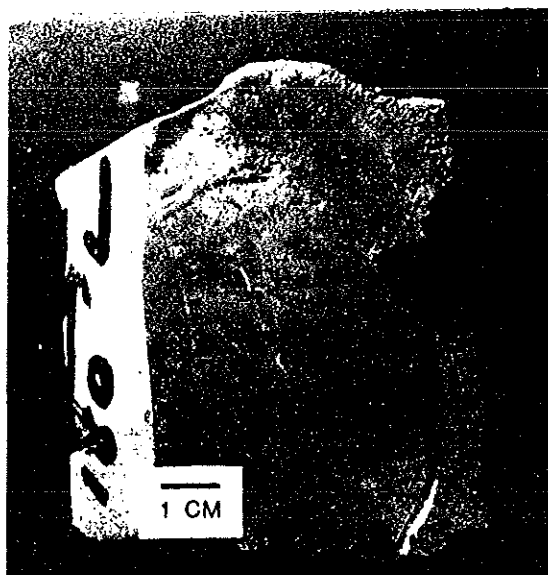
Severe Alteration and Brecciation

Ferruginous dolostone and limestone and brecciated dolostone are lithotypes displaying severe alteration and brecciation. These lithotypes were described in detail in the preceding lithotype descriptions.

Replacement by Quartz

Quartz is found only in minor amounts in the Interlake as a replacement mineral. It occurs as small chert nodules (Fig. 20A), which are richly fossiliferous in completely dolomitized sections, or as small patches of chalcedony or megaquartz that usually replaces dolomite cement in portions of the Interlake from deeper parts of the Williston Basin.

Figure 20. Photograph of a chert nodule (a). Core no.
548-180.



ENVIRONMENTAL INTERPRETATIONS

Introduction

Environmental interpretation of lithotypes in the Interlake Formation was accomplished by comparing information gained from detailed petrographic study of Interlake rocks (and their stratigraphic relationships) to information published in studies of modern and ancient carbonate. The Interlake Formation represents carbonate sediment that was deposited in an extensive epeiric sea which covered North Dakota, as well as surrounding areas, during Silurian time. Since there are no low-latitude epeiric seas in existence today (Garner, 1974, p. 661), carbonate geologists must use marginal marine carbonate environments for depositional models. However, ancient epeiric seas may have been very different from modern oceans. Shaw (1964, p. 7) states that epeiric seas had very low bottom slopes, much lower than slopes on modern continental shelves. Because these epeiric seas were so shallow, Shaw postulates that tidal swells developed in deeper water would impinge on the bottom, dissipating their energy at a point that was still a large distance from the edge of the epeiric sea. Garner (1974, p. 662) calculated that with a bottom slope of 0.1 ft./mi., and an average tidal wave base of 30 ft, this point of impingement would be 300 miles from the shoreline. This leaves a large expanse of epeiric sea behind the zone of impingement where normal,

daily tides would be effectively damped.

In constructing his model, Shaw (1964) assumed that the tides had to be generated in the deeper, open ocean, and that epeiric seas had a simple, consistent bottom geometry. It may be possible that epeiric seas were large enough to generate their own tidal systems, independent of the open ocean. It has been argued that tidal ranges during Early Paleozoic time were greater than they are today (Schopf, 1980, p. 83), and this extra tidal force possibly could have been enough to generate tides within epeiric seas, especially if bottom geometry of the seas differed from Shaw's simple model; i.e., became deeper behind the zone of impingement.

However, Shaw's arguments appear to be valid, and tidal ranges in epeiric seas were probably small. Yet Roehl (1967) demonstrated that fabrics and textures in Interlake carbonates along the Cedar Creek anticline in eastern Montana are strikingly similar to fabrics and textures on Andros Island in the Bahamas, a tide-dominated carbonate environment. Since tidal ranges were probably small, the most obvious source of energy to generate these deposits in an epeiric sea is movement of water by wind. The large expanse of epeiric sea landward of the zone of impingement could well have had enough fetch to allow generation of vigorous wave activity (Shaw, 1964, p. 35). Therefore, shallow-water to subaerial carbonate environments related to epeiric seas may have been dominated by wind-generated energy rather than true tidal energy.

The presence of tides in epeiric seas is a question that cannot be resolved easily. Because of this, the terms subtidal, inter-

tidal, and supratidal become less meaningful in a discussion of sedimentation in epeiric seas, due to their tidal connotations. Therefore, since winds could have generated swells and waves, and depositional environments somewhat analogous to modern tidal flats could have formed, the terms sublittoral, littoral, and supralittoral will be used in this paper. Although the idea of tidal action is also intrinsic to these terms, the writer feels that it is better to use existing terminology (Hedgpeth, 1957, pps. 18 and 20) that better fits an epeiric setting rather than to create new terminology. Therefore, the term sublittoral is used for all areas that were always submerged. Water depths during the time of deposition of Interlake sediments were probably no greater than the photic zone (as indicated by the presence of calcareous green algae). Where the bottom was below average wave base, low-energy conditions prevailed, while in areas above average wave base, relatively high-energy conditions prevailed. The littoral zone was that area influenced by fluctuations of the strandline caused by wind-generated high and low water. These types of fluctuations probably were sporadic, and sediment brought into the littoral zone would not have been reworked as vigorously as sediment on tidal flats at the margin of an open sea. The supralittoral zone is considered as that area above the average high position of the strandline and was only submerged by storm-generated high water. Sediment in the supralittoral zone would have been exposed most of the time, allowing desiccation. Sea water stranded in this zone would have concentrated to form brine pools.

Hard rain would have also disrupted sediment in this zone and periodically refreshed water in the brine pools. The high littoral and low supralittoral zones formed that area which was most often affected by fluctuations in the strandline and is here termed the littoral flat complex.

Interpretations for origins of the previously described lithotypes are given in order from the deepest sublittoral to supralittoral environments. Only depositional environments are here interpreted except in cases where diagenetic features were used to define a lithotype, and then these are also included in the discussion. Other diagenetic features are interpreted in the section of this paper on diagenesis.

Pelmatozoan Anthozoan Wackestone

An association of corals, pelmatozoans, brachiopods, trilobites, stromatoporoids, orthoconic cephalopods, and calcareous algae comprise a fauna and flora indicative of sublittoral environments with normal salinity (Heckel, 1972, p. 273). Remains of all of the above organisms are found in the pelmatozoan anthozoan wackestone lithotype. Therefore, the in situ corals and stromatoporoids together with the other unabraded skeletal allochems and the wackestone fabric of this lithotype suggest that these rocks represent deposition in sublittoral environments with normal salinity below normal wave base. The presence of calcareous algae in this lithotype suggests that water depths were not greater than the photic zone.

The pelmatozoan anthozoan wackestone lithotype may represent small carbonate buildups in the epeiric sea which covered North Dakota during Silurian time. "Meadows" of pelmatozoan echinoderms may have covered areas between these buildups as suggested by the abundance of pelmatozoan columnals in this lithotype. These possible buildups are found in areas along the Nesson anticline in western North Dakota, and are also present in NDGS 38 in Bottineau County. The fauna and flora which comprise these buildups are somewhat similar to the fauna and flora that comprise buildups of Silurian age in the Baltic Islands of Gotland (Wilson, 1975, p. 115), which are dominated by tabulate corals and stromatoporoids. The pelmatozoan echinoderm "meadows" also probably contained brachiopods in abundance.

The interpretation presented above for North Dakota Interlake rocks with a low-energy sublittoral origin is consistent with interpretations for similar rocks in the Interlake from Manitoba and Saskatchewan made by previous workers (e.g. Baillie, 1951; Stanton, 1953; Porter and Fuller, 1959; Andrichuck, 1959; King, 1964).

Ooid Grainstone

A modern environment in which ooids are the dominant constituent of the sediment is the ooid shoals forming today on the margin of the Great Bahama Bank. These shoals consist of long, narrow, bars which are cut by tidal channels (Harris, 1979, p. 5). The ooids in these shoals are composed of concentric layers of tangentially-oriented needles of aragonite which forms around a

nucleus grain (Harris, 1979, p. 5) in high-energy environments (Harris, 1979, p. 1).

The tangentially-coated ooids and the grainstone fabric which characterize rocks in the ooid grainstone lithotype thus suggest deposition in a high-energy sublittoral environment where ooids could have formed and mud could have been winnowed out of the sediment. Although enough data do not exist to determine the three-dimensional geometry of zones of the ooid grainstone lithotype, its petrographic similarity to sediment in modern ooid shoals suggests that this lithotype may have formed in a high-energy sublittoral environment. The presence of oncolites, or "unattached" stromatolites (Johnson, 1961, p. 206), intraclasts, and dendritic stromatoporoids in this lithotype does not necessitate a high-energy ooid shoal environment, but is consistent with this interpretation.

Peloidal Quartz Silt Packstone

Rocks in the peloidal quartz silt packstone lithotype are easily recognized by the presence of well-rounded peloids. A modern environment in which the sediments are dominated by well-rounded peloids is the intertidal flats on Andros Island, the Bahamas (Shinn and Lloyd, 1969). Peloids in modern tidal flats are interpreted as fecal pellets (Shinn and Lloyd, 1969, p. 1209). Peloids in the Interlake Formation may be fecal in origin, although there is no direct evidence to support this other than their morphologic and petrographic similarities to modern fecal pellets (see Shinn and Lloyd, 1969, Fig. 10C).

Gastropods, which occur locally in the peloidal quartz silt packstone lithotype, are typically whole and unabraded. This suggests that the gastropods were indigenous to the environment represented by this lithofacies. Gastropods are a common constituent in modern intertidal areas (Heckel, 1972, p. 237) and are an abundant component in intertidal sediment found on Andros Island tidal flats (Shinn and Lloyd, 1969, p. 1209).

The above analogies suggest that the peloidal quartz silt lithotype represents an environment similar to modern carbonate intertidal flats. Such an environment during Interlake time would have been the littoral zone on a littoral flat complex. Currents caused by fluctuations of water level in the littoral zone would sort the sediment, but might not have had enough energy to winnow away all the mud deposited in the littoral zone.

Quartz sand and silt in the peloidal quartz silt packstone lithotype, the source of which can not be determined with the available data, might have been transported into littoral environments by wind. Most of the high concentrations of quartz silt and sand are restricted to the sections sampled on the crest and flanks of the Nesson Anticline.

Primary sedimentary structures are generally lacking in rocks of the peloidal quartz silt lithotype. In sediment on modern tidal flats, primary sedimentary structures are usually destroyed by bioturbation. The paucity of bedding or laminations in the peloidal quartz silt packstone lithotype may have been due to bioturbation, but direct evidence of bioturbation is lacking.

Fenestral Peloidal Wackestone

Rocks in the fenestral peloidal wackestone lithotype are similar to rocks in the peloidal quartz silt packstone lithotype except that the former display well-developed fenestral porosity and contain more mud. This suggests that the fenestral peloidal wackestone lithotype was also deposited on a littoral flat complex, but not in the same area as the peloidal, quartz silt packstone lithotype.

Fenestral porosity is a common feature of littoral flat complexes (Wilson, 1975, p. 82) and is formed by gas bubbles produced by decomposition of organic matter (algae) entrapped in desiccating sediment (Wilson, 1975, p. 436). Therefore, the fenestral peloidal wackestone lithotype may represent higher littoral to low supralittoral areas where desiccation could occur between periodic wettings. Erosion surfaces indicate that the sediment became indurated and formed local hardgrounds during periods of desiccation and that these cemented surfaces were scoured during storms which crossed the littoral flats and deposited more sediment.

The fenestral peloidal lithotype in the Interlake is similar to fossil fenestral carbonates in the Ordovician New Market Limestone of Virginia (Grover and Read, 1978), which were interpreted as having been deposited on a littoral flat.

Ooid Intraclastic Wackestone

The ooid intraclastic wackestone lithotype is found in one core (NDGS 38) and forms a zone about 3 feet thick at the base of

the Interlake in a succession interpreted as littoral flat complex deposits.

Rocks of the ooid intraclastic wackestone lithotype contain several features which suggest a hypersaline pond environment on a littoral flat complex. Mudcracks are extremely common around supratidal and intertidal ponds on St. Croix, United States Virgin Islands. The mudcracks on St. Croix have raised centers between them which can be ripped up and transported into ponds to form elongate mud chips. The elongate intraclasts in the ooid, intraclastic grainstone lithotype may be mud chips which formed in a similar manner.

Ooids in the ooid, intraclastic wackestone lithotype are very small and display a well-developed radial fibrous microstructure which is different from the tangentially coated ooids in the ooid grainstone lithotype. The interpretation of ooid microstructure is controversial (Simone, 1981; Obelenus, 1983), but prevailing theory suggests that a radial fibrous microstructure is indicative of quiescent, hypersaline conditions (Halley, 1977; Obelenus, 1983; Simone, 1981). Loreau and Purser (1973) described modern ooids forming in the hypersaline water of the Persian Gulf. There, the calcite in the ooids is precipitating directly from sea water with a radial fibrous microstructure, but subsequent movement of the ooids by waves and currents flattens the fibrous crystals forming the typical tangential coatings of "normal" marine ooids. Therefore, preservation of a radial fibrous microstructure may require quiescent conditions and suggests the quiet, hypersaline conditions of a supralittoral pond. The dark, concentric laminae

within the larger ooids in the ooid intraclastic wackestone lithotype may represent dissolution surfaces caused by periodic influxes of fresher (rain or sea) water which allowed pond water to dissolve calcium carbonate.

Trilobite Mudstone

Trilobite mudstone is found only in one core (NDGS 1606) and forms several thin zones, some up to 1.0 feet thick, in sections which are interpreted as representing deposition in supralittoral and littoral environments.

A mudstone texture indicates quiet conditions in which mud could accumulate; black trilobite mudstone was deposited in quiet, anoxic subaqueous environments, while the gray varieties were deposited in quiet, relatively more oxygenated, subaqueous environments.

The fauna and flora preserved in the trilobite mudstone lithotype do not constitute a usual assemblage for either sublittoral, littoral, or supralittoral environments. Trilobites, the most abundant skeletal allochem, were exclusively marine organisms (Harrington, 1959, p. 40). If these trilobites were indigenous to the environment represented by this lithotype, then other organisms which were exclusively marine, such as echinoderms and corals, should also have been present. Instead, only a few ostracods, calcispheres, and gastropods are present in trilobite mudstone; and these only in the gray varieties. This assemblage of ostracods, calcispheres, and gastropods is more typical of restricted marine environments in modern settings (Heckel, 1972, p. 234).

The sporadic vertical distribution of trilobite mudstone in rocks which were probably deposited on a littoral flat complex indicates that the environment of deposition of this lithotype was short-lived and probably localized. Short-lived, subaqueous environments that occurred on littoral flat complexes were ponds. These ponds were only recharged during storm-high water, and were probably stagnant most of the time. Gastropods, ostracods, and calcispheres could have tolerated this type of environment, but trilobites probably could not have tolerated hypersaline or brackish water. Therefore, the trilobites were not indigenous to these ponds and their remains were probably transported as exuviae by storm waves and currents from the sublittoral environment.

Intraclastic Pelmatozoan Wackepackstone

The intraclastic pelmatozoan wackepackstone lithotype forms thin zones 1-3 feet thick and is associated with evaporitic rocks. Although a sublittoral assemblage is present in this lithotype, the abraded and imbricate nature of the allochems suggests that they were transported. These observations suggest that this lithotype was probably deposited on an arid littoral flat complex.

In modern supratidal areas which are, for the most part, hydrodynamically analogous to their epeiric supralittoral counterparts, storm waves are the only significant agents of deposition of marine sediment (Ball et al., 1967, p. 594). Therefore, the intraclastic pelmatozoan wackepackstone lithotype represents a storm-generated deposit on a littoral flat complex.

Jones and Dixon (1976) interpret similar, thin, fossiliferous beds, which occur randomly throughout the Read Bay Formation (Silurian), Arctic Canada, as storm deposits.

Stromatolite and Cryptalgal Dololamine

Modern algal-bound sediments occur in a wide variety of hydrodynamic and depositional environments. They occur, for instance, on Andros Island tidal flats (Hardie and Garrett, 1977, p. 20-50), on Persian Gulf Sabkhas (Shearman, 1978, p. 8), and in Sharks Bay, Australia (Hoffman, 1976, p. 261). When these modern analogs are applied to the ancient record in the Interlake, the morphology of the algal growths and the associated lithotypes are the best indicators of past depositional environments.

Generally, in modern marine environments, blue-green algae form mat-like structures in environments where wave and tidal scour are weak, and form columnar structures in marine environments where wave and tidal scour are strong; the relief of the column is proportional to the intensity of wave action (Hoffman, 1976, p. 270). In Sharks Bay, western Australia, large columnar algal growths are found in high-energy intertidal flats (Hoffman, 1976, p. 266). On Andros Island, algal-bound sediment occurs as small heads on intertidal channel banks, beach mounds, and beach ridges and as flat-lying mats on intertidal channel levee crests and back slopes (Hardie and Garrett, 1977, p. 20-50). On modern sabkhas along the Persian Gulf, algal growth is restricted to the intertidal zone where the algae form rubber-like mats several centimeters thick; these mats often contain vertically aligned,

lenticular, gypsum crystals and are associated with other evaporitic minerals (Shearman, 1978, p. 8).

Since ancient littoral flat complexes may have differed from modern tidal flat complexes, a precise analogy may not exist between the occurrence of algal stromatolites in ancient and modern environments. If daily tidal fluctuations were weak or absent, then algae which grew in the higher littoral and low supralittoral zones (littoral flat complex) and around channels would not have been affected by frequent influxes of marine water. Therefore littoral flat complexes were probably covered by flat-lying algae, as this morphology indicates low-energy conditions. Flat-lying stromatolites associated with evaporitic lithotypes, which contain evaporite minerals, formed in high littoral environments on arid littoral flat complexes similar to modern sabkhas. Columnar stromatolites in the Interlake may have formed in areas where wave action was strongest; this would have been that area of the littoral zone directly adjacent to the strandline. This area would have been influenced by the swash and backwash of waves, which would have entrained sediment and scoured the algal growths, causing them to take on a columnar morphology.

Cryptalgal dololaminates probably represent algal-bound sediment which formed in supralittoral environments where wave scour was generally absent. The thin, gray laminations may represent algal-bound surfaces while the tan interbeds may represent mud deposited by high water caused by storms. This type of process may have been similar to that described by Hardie and

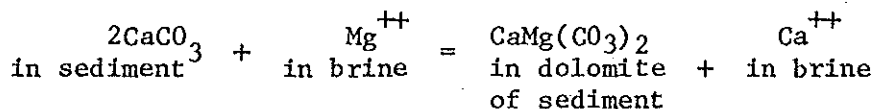
Ginsburg (1977, p. 97) for laminated, algal-bound sediment forming on Andros Island. Similar laminated dolostones in the Muav Limestone of the Grand Canyon, Arizona, have been interpreted as algal-bound sediment which formed on broad, supratidal beaches (Wanless, 1975).

Anhydritic Dolomitic Mudstone

The anhydritic dolomitic mudstone lithotype represents deposition in an arid supralittoral environment which may have been similar, in a climatic sense, to the coastal sabkhas of the Trucial Coast, Persian Gulf (see Shearman, 1978). The nodular types of anhydritic dolomitic mudstone represent supralittoral environments, while the laminar types represent subaqueous environments, such as supralittoral pools or salinas. Associated flat-lying algal mats and fossiliferous storm deposits support this interpretation.

Nodular types of anhydritic dolomitic mudstone are composed of anhydrite and dolomitic mudstone, similar to sediment of modern sabkhas. Nodular anhydrite grows in the sediment of modern sabkhas by displacement of surrounding material and tends to form in layers subparallel to bedding. These nodules grow by development of new crystals, not enlargement of older ones, resulting in aggregates of tiny, lath-shaped (felted) crystals (Shearman, 1978, p. 15). Anhydrite nodules in the anhydritic dolomitic mudstone lithotype are also composed of small, lath-shaped aggregates of crystals and appear to have grown displacively in the sediment, suggesting that they may have formed in a manner similar to modern anhydrite nodules.

The mudstone matrix surrounding the anhydrite nodules in the anhydritic dolomitic mudstone lithotype is composed of dolomite. On modern sabkhas, the sediment surrounding the anhydrite nodules is also dolomitic. This sediment, which accumulates in supratidal areas, is composed of aragonitic mud and pelleted aragonitic mud washed in from lagoons at high spring-tides and storms and of wind-blown carbonate sand (Shearman, 1978, p. 9). Sea water which washes in during high tides and storms concentrates by evaporation and begins to precipitate anhydrite, gypsum, and other evaporite minerals. This precipitation of sulfate minerals causes an increase in the Mg^{++}/Ca^{++} ratio of the brines in the sediment. When this ratio becomes high enough, the brines can dolomitize pre-existing aragonite and calcite by the reaction (Butler, 1969, p. 171):



Since there is indication that anhydrite nodules were present on Interlake arid littoral flat complexes, a similar concentration of sea water may have taken place causing dolomitization of carbonate mud deposited in these areas.

Modern salina sediments and the laminar types of anhydritic dolomitic mudstone both contain laminar evaporites, either pure or in douplets with carbonate, and rip-up breccias. Laminations in Interlake laminar evaporites may be parallel or somewhat undulating, similar to evaporite and carbonate laminations in modern salinas as described by Schreiber (1981, p. 19). The gypsum in modern salinas forms either as a crust of

elongate crystals on the bottom or as free-floating, acicular crystals; these crystals tend to have a preferred orientation parallel to bedding (Schreiber, 1981, p. 19). The lath-shaped anhydrite crystals which are parallel or subparallel to bedding in laminar types of anhydritic dolomitic mudstone may have formed in an analogous manner, and may have been gypsum when they were deposited but may have subsequently undergone dehydration to form anhydrite.

In modern salinas, rip-up breccias form in muddy sediment during periods of desiccation (Schreiber, 1981, p. 19). The small, imbricate mud clasts in the laminar types of anhydritic dolomitic mudstone of the Interlake may be rip-up breccias which were produced in the fashion described by Schreiber (1981).

Mudstone

Mudstone is found throughout the Interlake Formation intercalated with other lithotypes. This indicates that mudstone may have had a variety of origins, and that mudstone, per se, is not indicative of any particular depositional environment.

In modern marine environments, carbonate mud may be produced by physical breakage and abrasion of carbonate grains (Matthews, 1966), by epibionts on sea grass (Patriquin, 1972), by breakdown of calcareous algae (Stockman et al., 1967), or by direct precipitation from sea water (Cloud, 1962).

None of these sources can easily be documented in the Interlake; the best interpretation that can be made is that mudstone

in the Interlake may have had a variety of origins. Most of the mud may have been derived from the sublittoral environment by processes similar to those now producing mud in modern subtidal carbonate environments. Therefore, most of the mudstone found in rocks of littoral and supralittoral origin in the Interlake may represent mud that was transported during storm-high water into those environments from sublittoral environments; while mud in sublittoral environments may have formed in situ.

Burrowed mudstone suggests bioturbation, perhaps by soft-bodied organisms, in both littoral, supralittoral, and sublittoral environments. Burrows are a common feature present in other ancient carbonate rocks (Kahle and Floyd, 1971, Table 4), but are not often preserved in Interlake rocks and are not useful in this study for environmental interpretations.

Ferruginous Dolostone and Limestone and Brecciated Dolostone

Ferruginous dolostone and limestone and brecciated dolostone are lithotypes dominated by diagenetic features. Both of these lithotypes probably represent weathered horizons; the ferruginous dolostone and limestone lithotype would be classified as ferricrete, and the brecciated dolostone lithotype a (dolomitic) calcrete.

Ferruginous Dolostone and Limestone

Ferruginous dolostone and limestone are dominated by features suggesting that severe alteration of carbonate material took place during periods of subaerial exposure and weathering during Interlake

time. Breccias and vugular porosity are characteristic features of both this lithotype and modern weathering horizons developed on carbonate rocks. In modern carbonate vadose diagenetic environments, where soil profiles form, infiltration by meteoric water under-saturated with respect to calcium carbonate causes extensive dissolution of limestone; this forms vugs and collapse breccias (Longman, 1980, p. 473).

Clasts of dolostone in ferruginous dolostone and limestone are angular, and may have their long axes vertical, suggesting that they were not transported. Therefore, these clasts may represent in situ brecciation of Interlake carbonates caused by meteoric water which dissolved these rocks in the vadose zone.

The presence of pendant or gravity cement on clasts and in vugular porosity in Interlake ferricrete also suggests a vadose diagenetic environment. Pendant cement is extremely common in modern vadose environments. It forms because air is present in pore spaces; this allows water droplets to hang from any free surface. As this water evaporates, carbonate is precipitated, forming a downward-elongate growth, or stalactite (Longman, 1981, p. 101). The processes by which pendant cement formed in Interlake ferricretes were probably similar to those processes active today in modern vadose environments.

Interlake ferricretes contain a ferruginous matrix which locally contains ferruginous ooids and pisolites. Similar ferruginous ooids and pisolites are now forming in pedogenic ferricretes on the Ivory Coast, Africa (Nahon et al., 1980, Fig. 8,

p. 1296). These ooids and pisolites form by (Nahon et al., 1980) "successive centripetal concentrations and reorganizations of iron oxides and hydroxides" (p. 1295). Since there is such striking petrographic similarity between the Ivory Coast ooids and pisolites and Interlake ferricrete ooids and pisolites, a similar mechanism may have been responsible for the formation of both.

Ivory Coast ferricretes are forming in a wet, tropical climate, and although the writer hesitates to draw any climatic analogies, this may indicate that the vadose zones where Interlake ferricretes formed were characterized by relatively wet conditions.

Brecciated Dolostone

Collapse breccias, vugular porosity, and micrite coatings are all features common to Interlake brecciated dolostone and to calcretes forming on Barbados as described by James (1972). Two major diagenetic changes are taking place in Barbados calcretes: alteration of original limestone and precipitation of new carbonate in the form of crusts and nodules (James, 1972, p. 822).

Alteration of the limestone is caused by solution and brecciation, recrystallization, and micritization. Solution and brecciation creates angular clasts and an irregular network of fractures in the limestone. In particular, allochems become separated from enclosing muddy matrix by cracking around the grains (James, 1972, p. 822). The most common type of recrystallization is micrite recrystallizing to microspar. Micritization can be extensive, with dark micrite totally replacing

allochems. Precipitation of new carbonate in calcretes from Barboados forms laminated crusts, coatings on allochems, fibrous cement, and micrite grains (James, 1972, p. 825).

Allochems in the brecciated dolostone lithotype are composed of dark, microcrystalline carbonate, and are commonly separated from their surrounding matrix. Microbrecciation and laminar coatings and crusts are also present. These features are probably analogous to similar features found in modern calcretes, suggesting that the brecciated dolostone lithotype represents a calcrete which formed as a result of extensive weathering of Interlake rocks in the vadose diagenetic environment. Pisolite-sized spherulites in these possible calcretes may represent "cave pearls" formed in voids created by dissolution and brecciation. Modern cave pearls are generally composed of radial-fibrous carbonate (Bathurst, 1975, p. 81); a microstructure similar to the spherulites in Interlake calcretes.

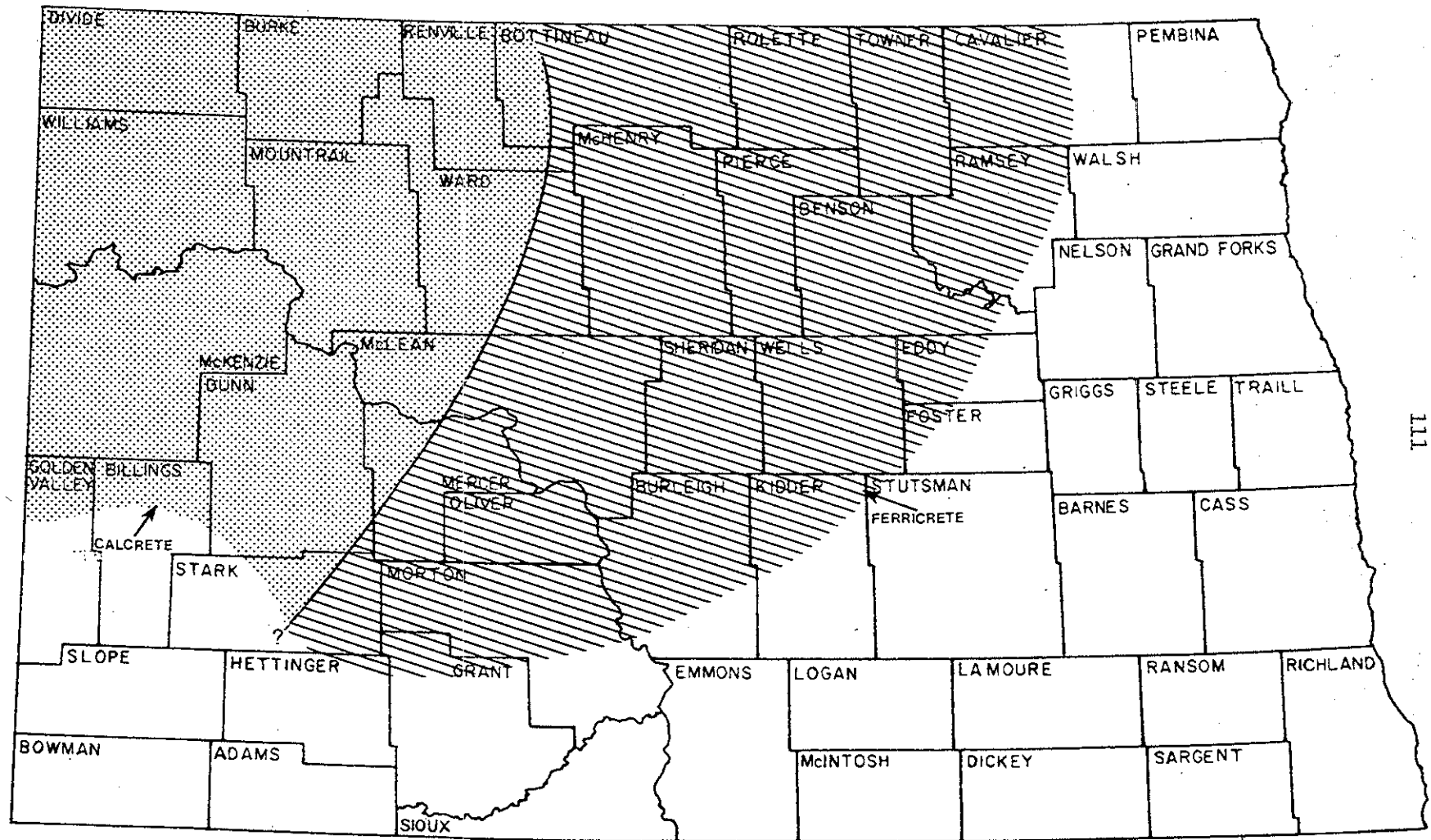
Harrison and Steinen (1978) interpreted brecciated and altered horizons in Mississippian rocks from Kentucky as paleo-exposure surfaces. These horizons contain micrite laminations, a peloidal micrite matrix, fractures, and pendant cement; all of these features are present in the brecciated dolostone lithotype.

The best-developed, modern calcrete profiles are products of hot, semi-arid areas (Reeves, 1976, p. 6). Again, the writer hesitates to draw climatic analogies, but the vadose zones where Interlake calcretes formed may have been characterized by relatively dry conditions.

Ferricretes and calcretes in the Interlake were sampled most often at the contact between the Ashern and Interlake Formations, although they occur within the Interlake as well. Calcretes were found in the center of the Williston Basin in western North Dakota while ferricretes were found in eastern and central North Dakota (Fig. 21). Since there probably were not any major topographic elements in the Williston Basin during Silurian times, the paleoclimate may not have been drastically different across the basin; it was probably not different enough to cause the distribution of paleosol types shown on Figure 21. Perhaps this distribution of paleosols may be explained by differences in the substrate in which these soil profiles developed.

Rocks in the western part of North Dakota are generally coarser-grained than those found in the eastern part of North Dakota. Packstones and grainstones, which predominated in the western area, would have been relatively more permeable than the wackestones and mudstones which predominated in the eastern area. Permeable, coarse-grained rocks would have allowed meteoric water to percolate into the subsurface, resulting in a relatively dry vadose zone. Finer-grained, more impermeable rocks would have inhibited downward percolation of meteoric water, producing relatively wetter vadose conditions. Even though the paleoclimate was probably similar across the Williston Basin at this time, calcretes would have formed in areas where the vadose zone may have been relatively dry, due to permeable substrate (now in western North Dakota), while ferricretes would have formed in areas

Figure 21. Map of North Dakota showing the approximate distribution of calcrete (stippled pattern) and ferricrete (diagonal pattern) located at the top of the Interlake Formation.



where the vadose zone may have been relatively wet, due to more impermeable substrate (today in the eastern and central parts of North Dakota) .

INTERLAKE DEPOSITIONAL MODEL

Numerous authors (e.g., Laporte, 1967; Lucia, 1968; Matter, 1967; Roehl, 1967) have listed criteria indicative of ancient supralittoral, littoral, and sublittoral environments, using modern analogs (e.g., The Great Bahama Bank and the Persian Gulf) as evidence. In these studies, however, there is a large overlap of diagnostic features between environments, particularly in the supralittoral and littoral zones (Table 2; Kahle and Floyd, 1971, Table 4).

Studies of modern carbonate environments (Shinn and Lloyd, 1969; Hardie and Garrett, 1977) have shown that sedimentary environments, particularly in the intertidal zone, are roughly perpendicular to the shoreline, rather than parallel to it. Supratidal levee crests occur laterally adjacent to intertidal channels in Bahamian tidal flat complexes (Hardie and Garrett, 1977, p. 15). This trend is counter to the overall "classical" model of environmental belts being parallel to the strandline (Fig. 22). Littoral flat complexes developed in the Interlake epeiric sea probably exhibited reentrants similar to modern carbonate shorelines. If these reentrants migrated laterally, a vertical succession of lithologies would have formed that would normally be interpreted as the result of fluctuations in sea level.

The lateral and vertical variability of lithotypes in the Interlake does not allow for detailed correlation. However, gross

Table 2. Some diagnostic features of supralittoral and littoral environments.

SUPRALITTORAL

- Roehl (1967) laminated dolomite
 algal mats
 flat pebble breccias or conglomerates
- Laporte (1967) dolomitic laminated mudstones
 mudcracks
 birdseye texture
 fossils scarce
 algal laminae
 burrows
- Matter (1967) discontinuous laminations
 mudcracks
 fossils scarce
- Lucia (1968) irregular laminations
 lithoclasts
 LLH algal stromatolites
 some mudcracks
 thin sandy beds
 fossils scarce

LITTORAL

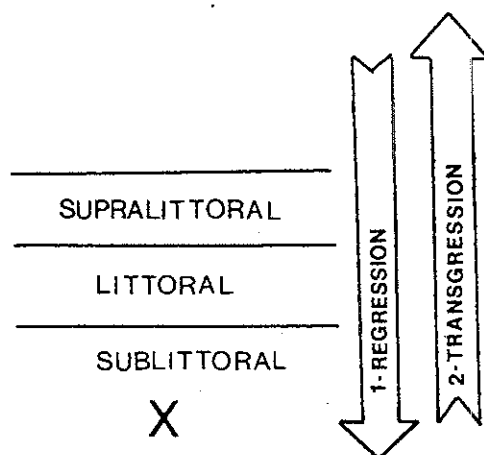
- Roehl (1967) argillaceous burrows
- Laporte (1967) interbedded pellet mudstone and skeletal
 calcarenite
 some pebble conglomerate and mudcracks
 fossil types few but individuals abundant
 algal stromatolites and oncolites
- Matter (1967) LLH stromatolites
 ribboned sediment
 mudcracks
 birdseye texture
 edge-wise conglomerates
 very few fossils

Figure 22. Interpretations of the same hypothetical vertical section using classical and actualized depositional models. "A" represents classical onlap and offlap, "B" represents vertical stacking of laterally adjacent environments due to lateral migration.

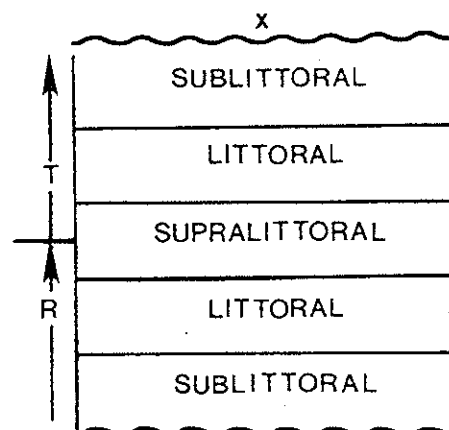
A

CLASSICAL MODEL

PLAN VIEW



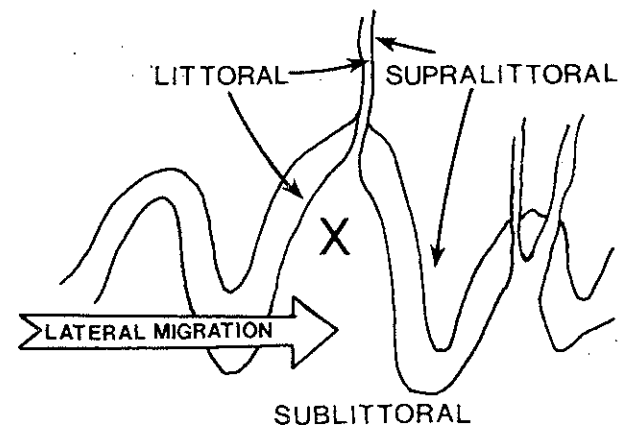
VERTICAL SECTION
AT POINT



B

ACTUALIZED MODEL

PLAN VIEW

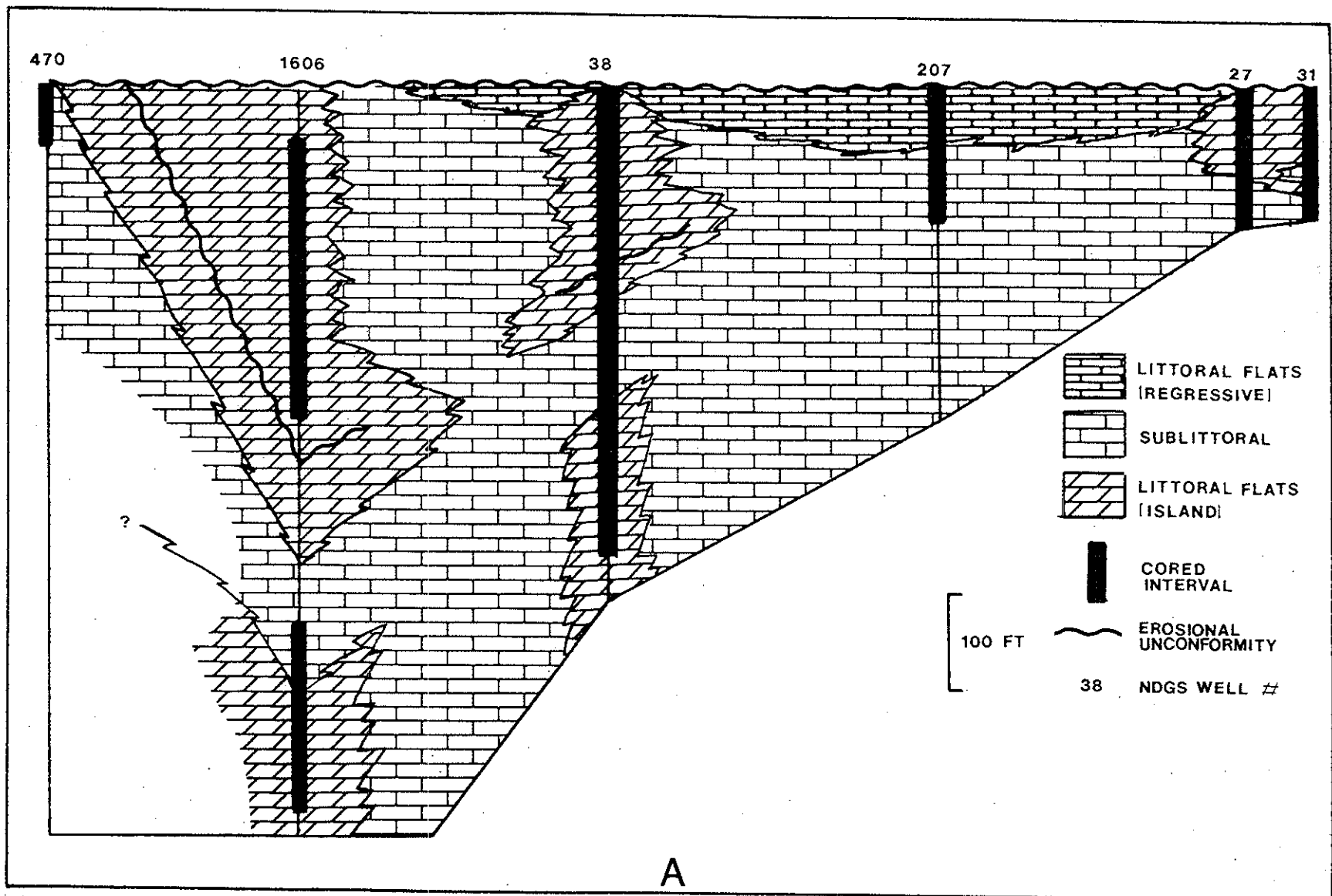


correlation of thick successions of rock which represent littoral flat complex or sublittoral environments can be done (Fig. 23). The vertical and lateral distribution of these successions suggests that the littoral flats that developed in the Interlake epeiric sea formed as islands.

Therefore, the depositional model for the Interlake consists of islands surrounded by low-energy and high-energy sublittoral environments (Fig. 24). Low-energy sublittoral environments (area A on Fig. 24) surrounded these islands and were characterized by muddy sediment upon which corals, stromatoporoids, echinoderms, brachiopods, and trilobites lived (pelmatozoan anthozan lithotype). Closer to these islands the epeiric sea became shallower causing waves to impinge on the bottom. Higher-energy conditions would have prevailed in this environment (area B on Fig. 24) allowing ooids to form (ooid grainstone lithotype). Sediment along the strandline of these islands would probably have consisted of peloids (fecal pellets?), gastropod shells, debris and mud washed in from sublittoral environments, and wind-blown material (peloidal quartz silt packstone lithotype). Columnar algal growths would have formed in this area (columnar stromatolites). Similar sediment which was deposited further away from the strandline, in high littoral and in supralittoral areas, would have undergone desiccation and formed fenestral porosity (fenestral peloidal wackestone lithotype). If arid conditions prevailed, evaporite minerals would have precipitated in supralittoral environments

Figure 23. Distribution of island and sublittoral rock rocks in North Dakota

- A) Cross section of the Interlake Formation in North Dakota showing the vertical and lateral distribution of rock types that represent sublittoral and island environments. The littoral flats represented by the dolomite pattern formed on islands which developed on topographic highs. The littoral flat complexes represented by the small-brick pattern developed as the epeiric sea was regressing from North Dakota at the end of Silurian time.
- B) Location map for cross section in Figure 23A.



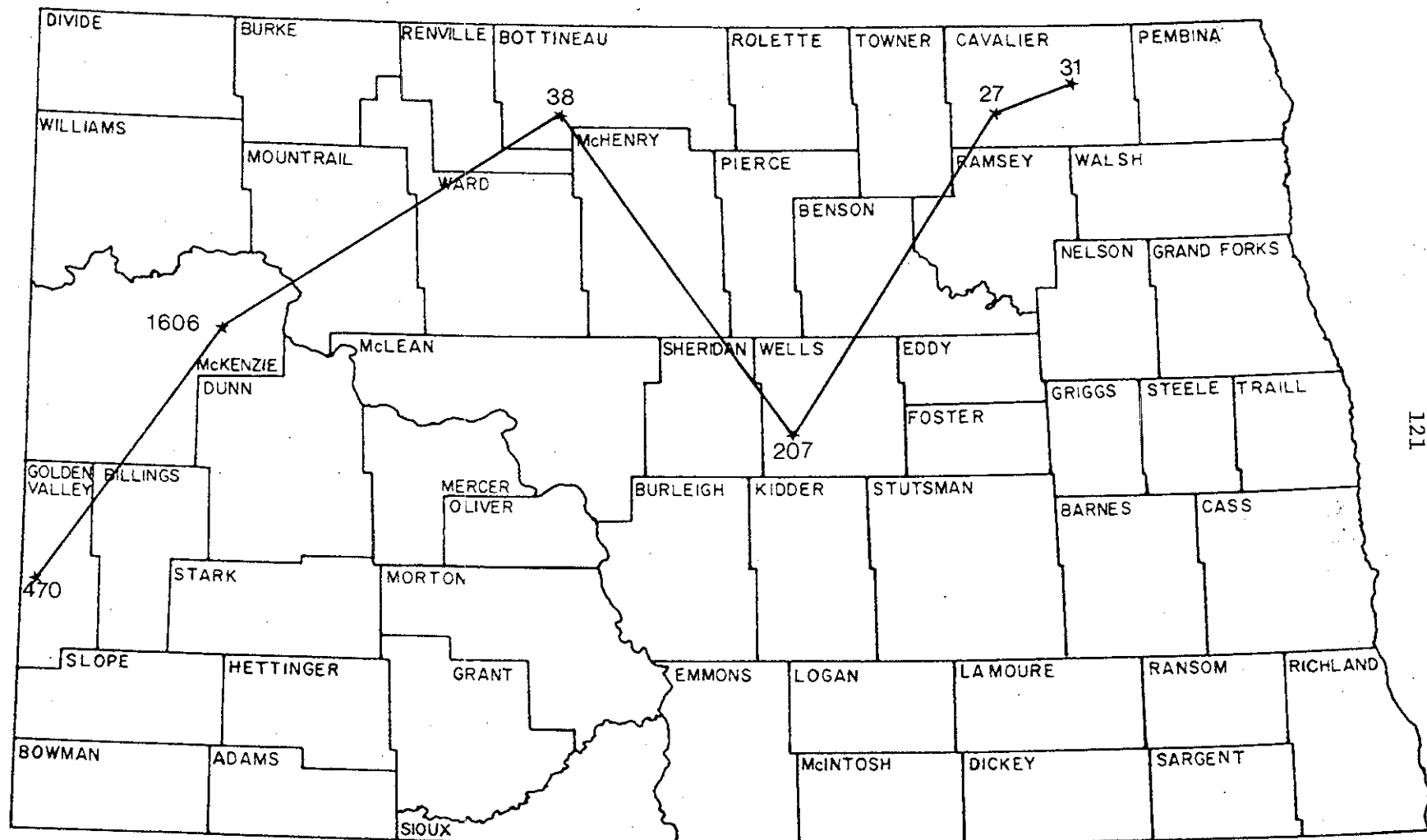
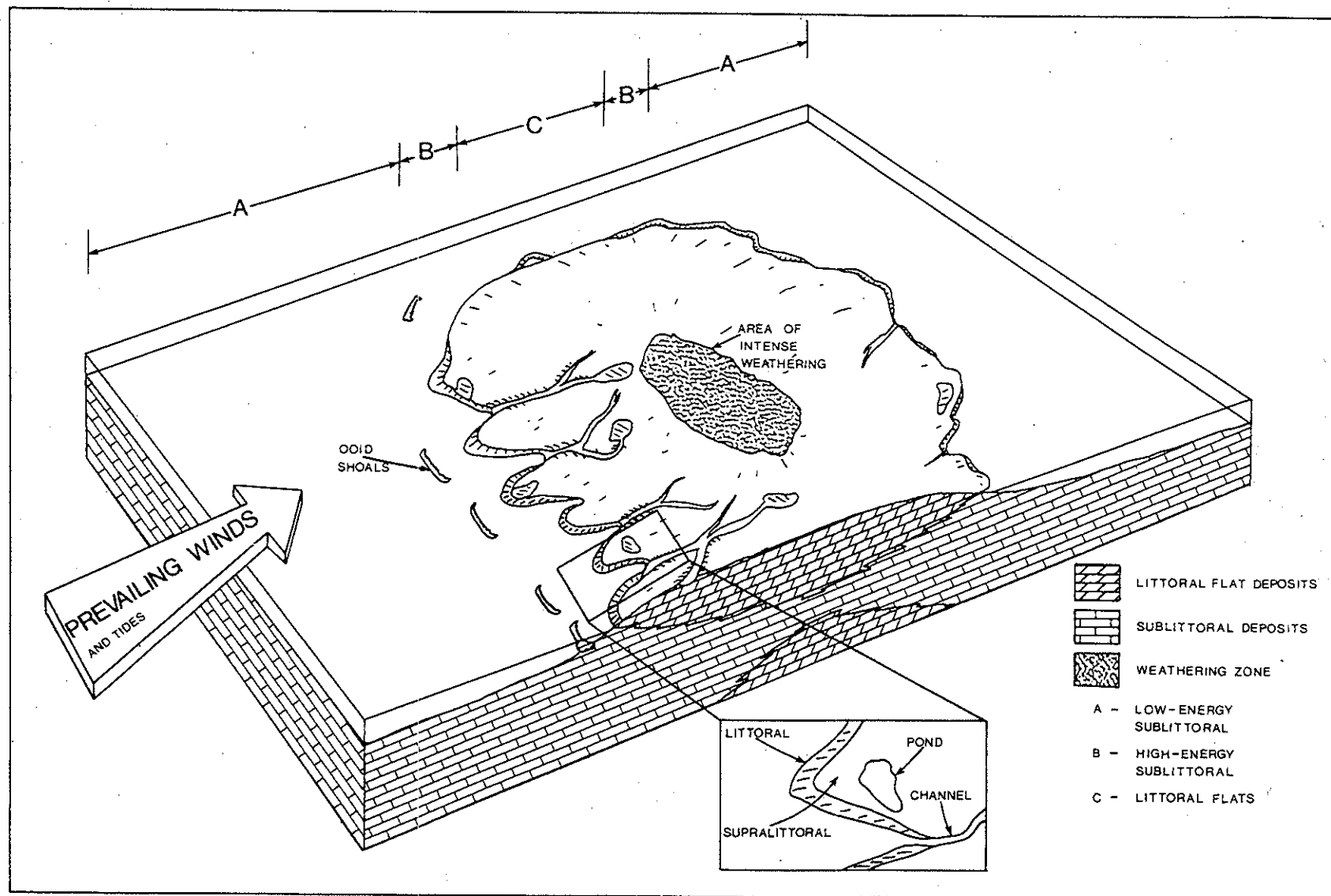


Figure 24. Block diagram of depositional model for islands that developed on topographic highs in the Interlake epeiric sea. No scale intended.



(nodular type of anhydritic dolomitic mudstone lithotype). Flat-lying algal growths would also have occurred in supralittoral and high littoral areas (flat-lying stromatolite and cryptalgal dololaminate). Storms could have washed in skeletal debris from sublittoral environments, depositing thin fossiliferous units on littoral flat complexes (intraclastic pelmatozoan wackestone lithotype). Ponds on littoral flat complexes could have been hypersaline (laminar type of anhydritic dolomitic mudstone, and ooid intraclastic wackestone lithotype) or brackish (trilobite mudstone lithotype?), and were probably short-lived. Once these islands became large enough, even the highest storm waves could not have covered their entire expanse. Therefore the carbonate material near the center of these islands probably underwent subaerial weathering and soil profiles developed. The most diverse lithotypes would have developed on the littoral flat complexes. If environments within these complexes migrated laterally, the resultant mosaic of lithotypes would be characterized by generally thin, discontinuous rock types, similar to the pattern seen in the Interlake.

This depositional model shows that each of the lithotypes in the Interlake could have been developed contemporaneously in laterally adjacent environments. Local migration of subenvironments and regional migration of major environments in response to changes in the position of the strandline produced a complex mosaic of lithotypes in North Dakota during Interlake time.

DEPOSITIONAL HISTORY OF THE INTERLAKE FORMATION

Introduction

Epeiric seas, by definition, occurred upon continents, had large areal extents, and have very shallow water depths (Shaw, 1964, p. 5). Important controls on sedimentation in epeiric seas were:

- 1) external tectonic influences and epeirogenic movements,
- 2) slope of the sea bottom (shape of the basin) and
- 3) local topography.

The first item listed may have been the most fundamental and therefore the most important factor controlling epeiric sedimentation, because major transgressive and regressive cycles (i.e., the intracratonic sequences of Sloss, 1963) may have been controlled by external tectonic events (Johnson, 1971). However, this topic is beyond the scope of this study and will not be discussed further. The second and third items listed above were important because once transgression or regression was initiated, the slope of the sea bottom and local topography controlled local water depth, water energy, and sediment distribution.

The slope of the bottom in epeiric seas was very gentle, perhaps 0.1 to 0.5 feet per mile (Shaw, 1964, p. 63). Because of this gentle slope, environmental (and sedimentary) zones that developed within epeiric seas (assuming that the bottom of the epeiric sea was not broken by local topography) would have been

characterized by broad environmental zones oriented parallel to the edge of the epeiric sea (Shaw, 1964, p. 46; Irwin, 1965, p. 450). If the flat bottom of the epeiric sea was broken by local topographic highs, the resultant environmental pattern would have been modified from those predicted by simpler models. Topographic highs in epeiric seas would have created local shoaling areas which resulted in environmental conditions that were not normally present in epeiric seas--high-energy littoral flat complexes. In addition, slopes adjacent to the local highs would have been greater than the average value for epeiric seas and environmental zones around the highs would have been narrower than those predicted by the general model.

Silurian rocks in the Williston Basin are an isolated remnant of sediments deposited in an extensive epeiric sea which covered most of the North American Craton (Sloss, 1963, p. 99). Shaw (1964) proposed that areas in epeiric seas landward of the zone of wave impingement would have been characterized by muddy sediment which contained evaporite minerals (assuming an arid climate). The rock types found in the Interlake do not fit this model. The extreme vertical and lateral variability of lithologies in the Interlake suggests that the lateral development of depositional environments during Interlake time, and their migration through time were equally varied. This pattern is much more complicated than the pattern predicted by Shaw (1964) for epeiric seas. Therefore, the extreme lateral variability of environments in the Interlake epeiric sea may have been created by point sources

of carbonate littoral flat deposition, islands in the epeiric sea, rather than by broad, regional depositional zones.

Irwin (1965) divided epeiric seas into three energy zones (X, Y, and Z). The X zone was that area farthest offshore where the sea bottom was beneath wave base and was characterized by low-energy bottom conditions. The Y environmental zone was that area where waves would have first impinged on the bottom of the epeiric sea and was characterized by high-energy conditions. The Z environmental zone was that area landward of the Y zone and was characterized by low-energy conditions (Irwin 1965, p. 450). The islands in the Interlake epeiric sea developed as a result of topographic highs in the Z environmental zone of Irwin (1965) which allowed local, higher-energy Y zone shoaling conditions to form on top of the high areas (Fig. 25). Once enough sediment had accumulated on these highs to break the water surface, islands could have developed. If sediment, transported by wind-generated waves, continued to accumulate, the shorelines of these islands would have begun to prograde away from each high in all directions. Sediment characterized by packstone and grainstone textures, distinctly different from the muddy sediment usually associated with the Z zone would have developed on these islands; the environmental zones around them would have been narrower than Irwin's (1965) large zones which developed parallel to the periphery of the epeiric sea.

Most of the possible topographic highs identified in this study (e.g. the Nesson anticline) appear to be structurally

Figure 25. Comparison of Irwin's (1965) model for the distribution of environmental zones in epeiric seas to the model proposed for the Interlake Formation.

A IRWIN MODEL

LOW ENERGY X HIGH ENERGY Y LOW ENERGY Z

TOPOGRAPHIC HIGH TRANSPOSES Y ZONE INTO X ZONE

B INTERLAKE MODEL

X Y Z

TOPOGRAPHIC HIGH TRANSPOSES Y ZONE AND LITTORAL FLATS INTO Z ZONE

NOT TO SCALE

NOT TO SCALE

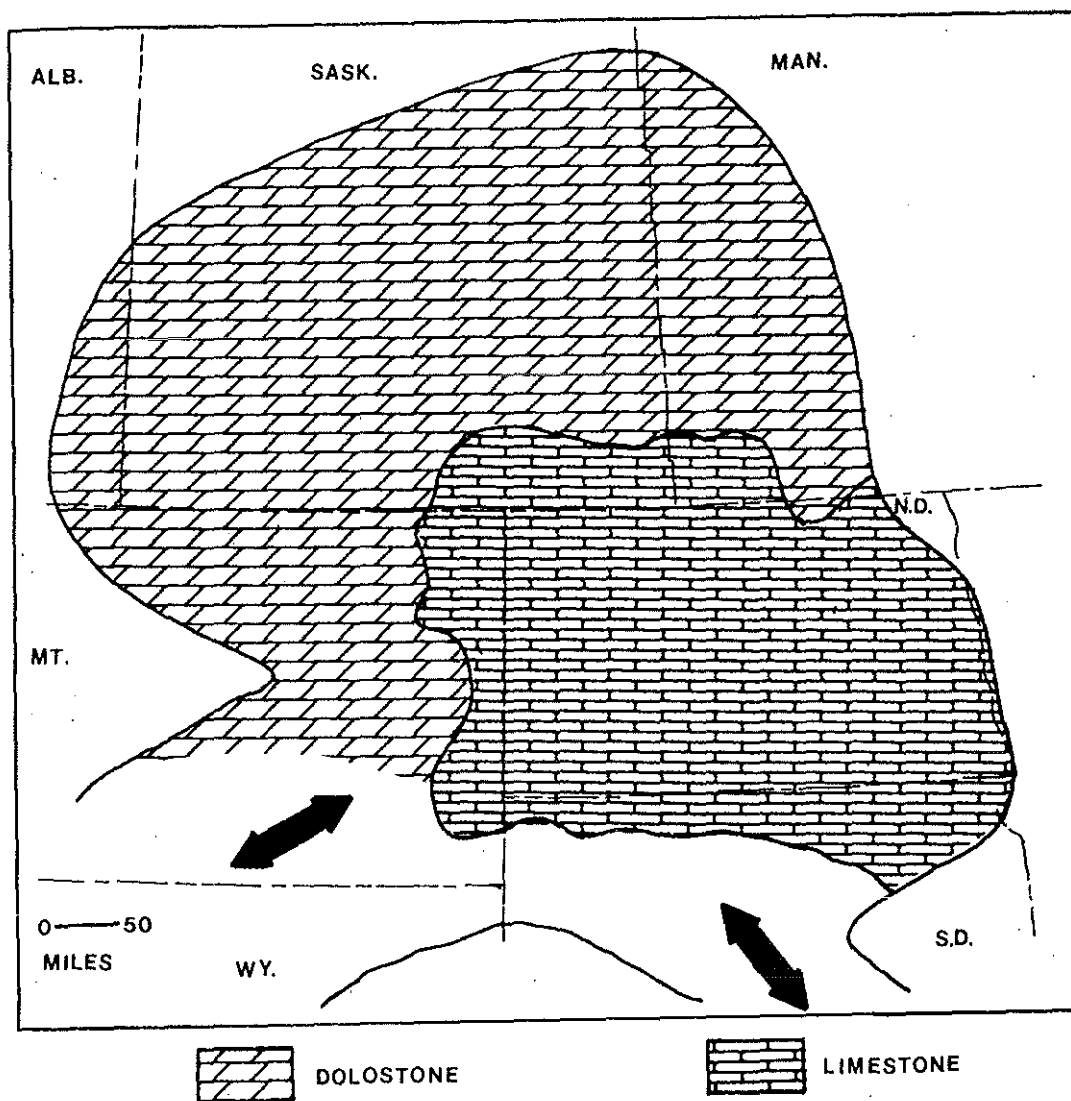
controlled. Both the Nesson and Cedar Creek anticlines, two of the largest structural elements within the Williston Basin, have histories that began in the Precambrian. The Nesson anticline was a high during Cambrian and Ordovician time; movement was controlled by faulting and uplift (Gerhard et al., 1972, p. 1000). Other basement structures, which manifest themselves as lineaments, have been documented in the Williston Basin and appear to have controlled past sedimentation patterns (Brown, 1978; Shurr, 1982; Sturm, 1982). These basement structures probably influenced Interlake sedimentation.

Depositional History

The regional geologic setting during Silurian time in North Dakota can be summarized as follows. The Williston Basin was a shallow depression in the North American craton containing several minor structures (Gerhard et al., 1982, p. 991) which created local topographic elements, most importantly, topographic highs. The paleoequator probably was just south of the Williston Basin during Silurian time (Dott and Batten, 1976, p. 252). Available evidence suggests that initial transgression of the epeiric sea came from the southwest, through a marine connection to the Cordilleran miogeosyncline (Gerhard et al. 1982, p. 999) although others may have existed (Fig. 26).

The depositional history of the Interlake has been divided into six major stages, each of which probably represents a time-transgressive event. The stages in this history (correlated by letter to Figure 27) are:

Figure 26. Map showing the possible marine connections during Ordovician and Silurian time in the Williston Basin. Modified from Gerhard et al., (1982).



- A) Initial onlap.
- B) Complete inundation.
- C) Growth and progradation of littoral flats.
- D) Onlap and reworking of calcretes and ferricretes.
- E) Major regression and formation of additional calcretes and ferricretes.

Paleogeographic reconstructions of these events are shown on Figure 27.

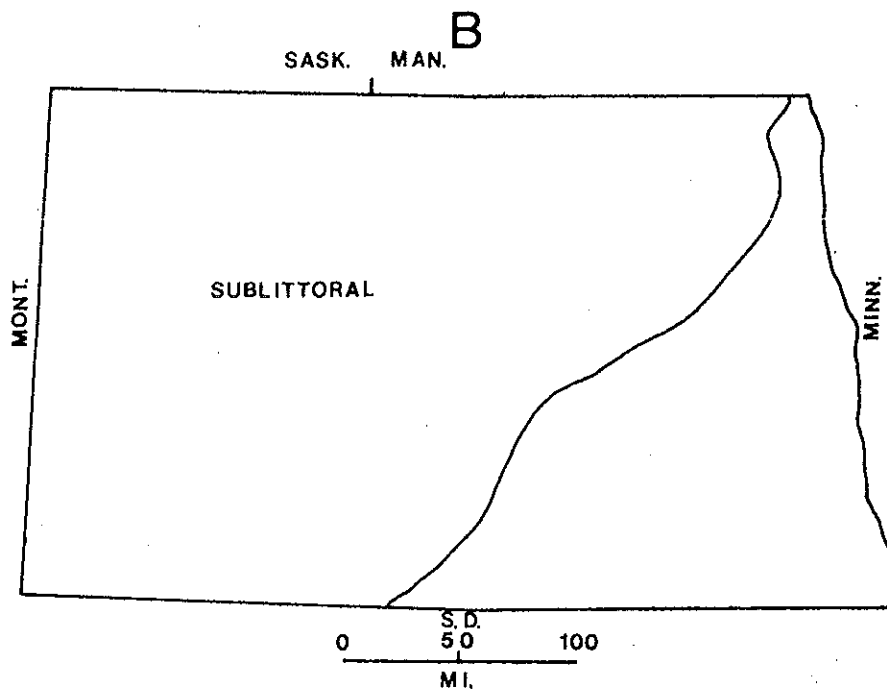
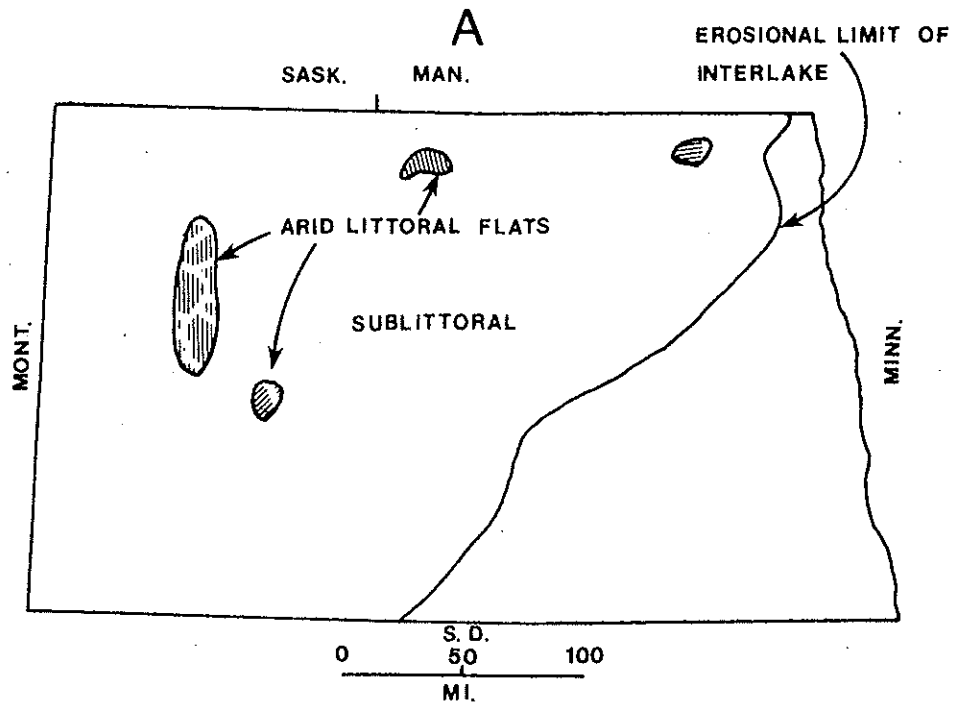
Although the Stonewall Formation is rarely cored, available core data suggest it is always similar in character to the overlying Interlake Formation. This similarity is so striking that no contact can be easily recognized in the core. The few cores studied of lower Interlake and Stonewall rocks suggest that arid littoral and supralittoral environments existed along the Nesson Anticline, as well as other high areas (in central Bottineau County), and were surrounded by sublittoral environments. Anhydrite nodules formed in supralittoral sediment and subaqueous laminated anhydrite formed in supralittoral ponds on the Nesson Anticline. Hypersaline ooids formed in supralittoral ponds in littoral flat complexes on the high in central Bottineau County. Richly fossiliferous storm deposits associated with these environments suggest that sublittoral environments flanked these littoral flat complexes. Stromatolites formed thick accumulations in littoral and supralittoral environments.

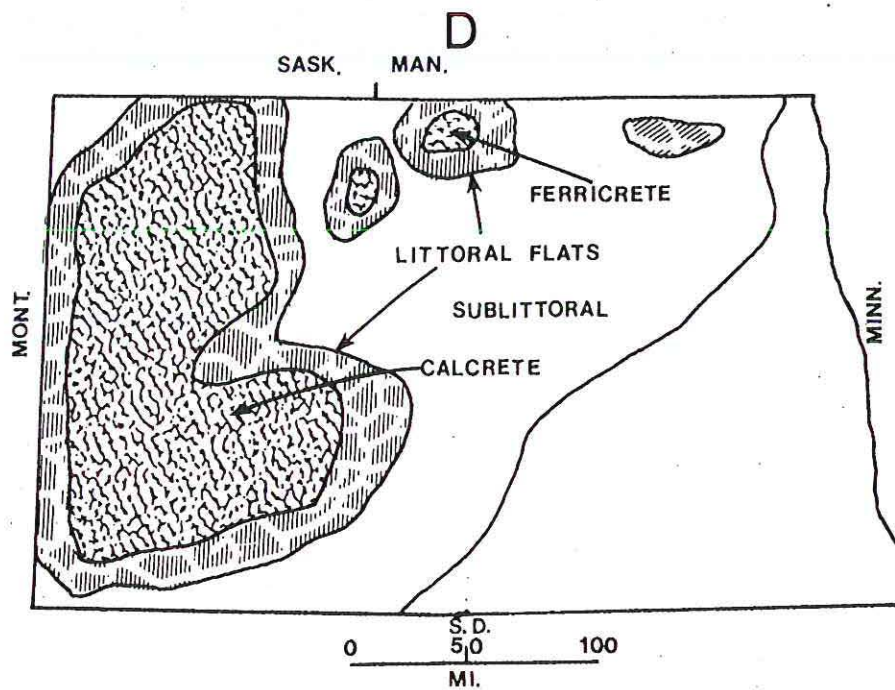
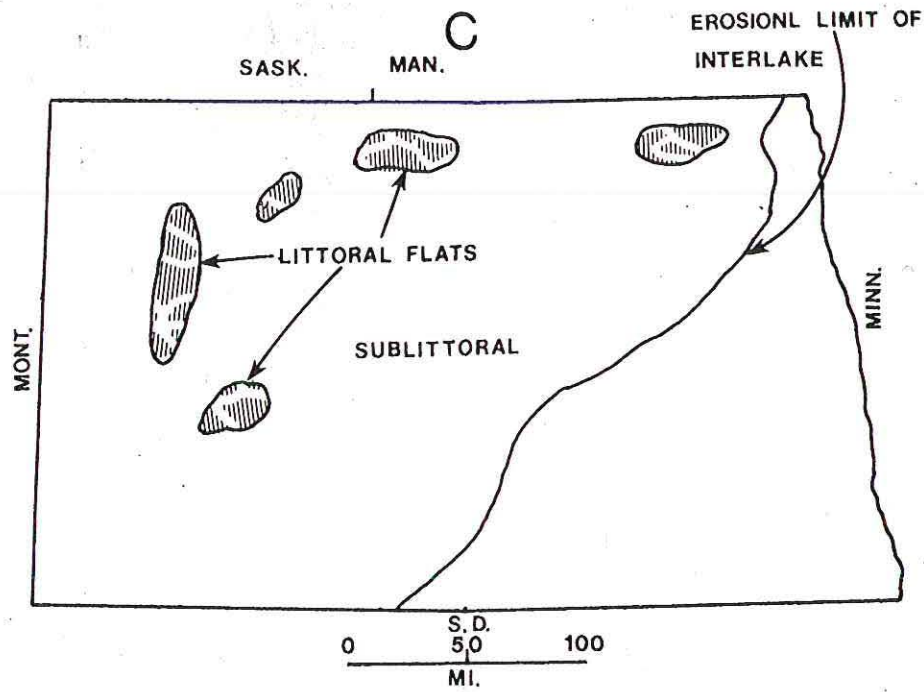
Stage A: Initial onlap

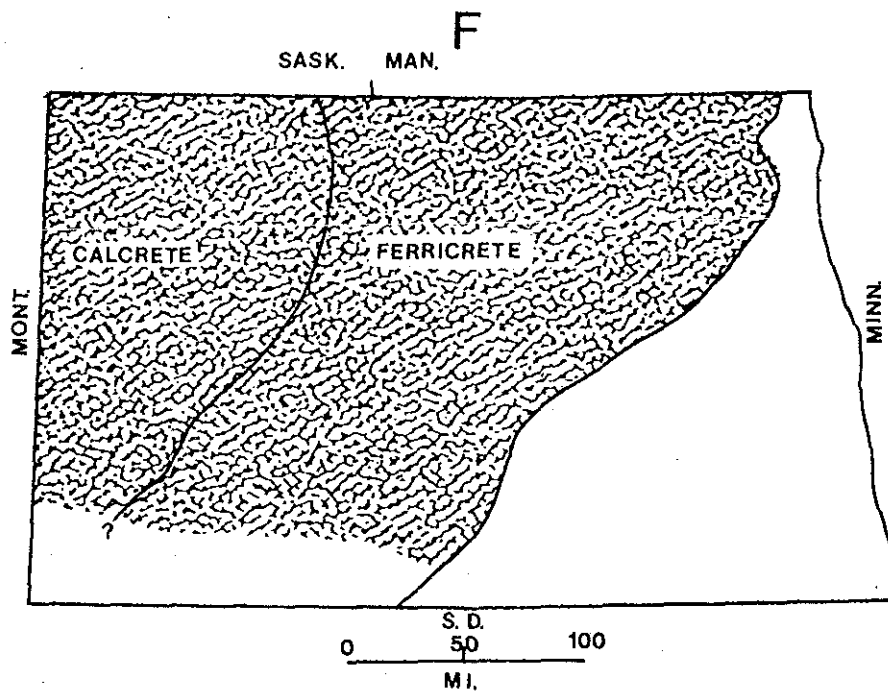
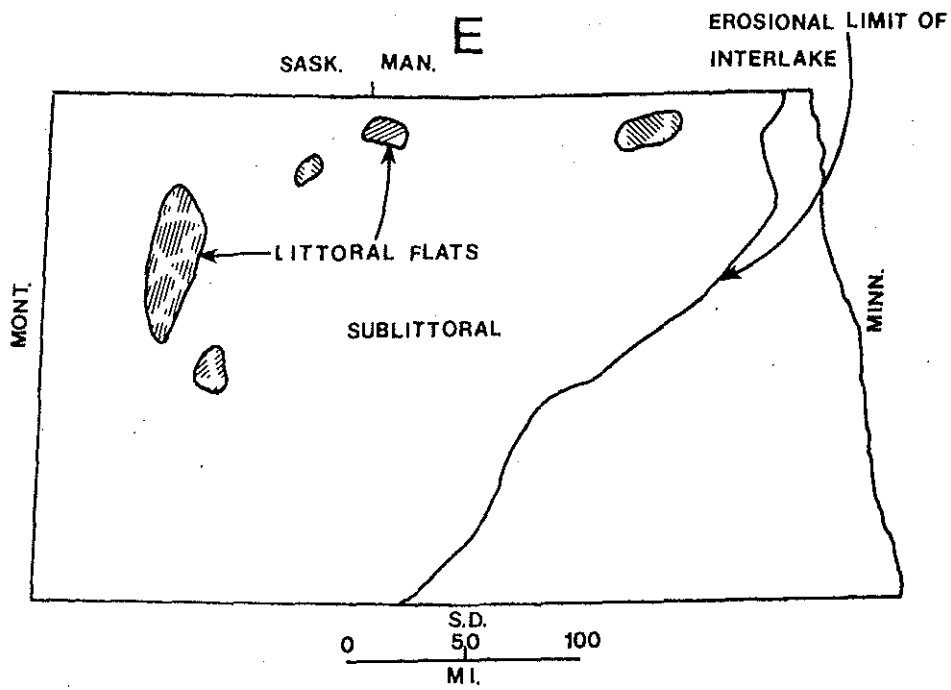
The first major event during Interlake time was onlap of

Figure 27. Paleogeographic reconstructions for the Interlake Formation.

- A) Islands developed on topographic highs at the beginning of Interlake time.
- B) Total inundation of the North Dakota part of the Williston Basin.
- C) Redevelopment of islands on topographic highs.
- D) Maximum areal extent of islands and intra-formational paleosols.
- E) Total regression of the epeiric sea from North Dakota and formation of state-wide paleosols.
- F) Relative rise in sea level causes partial inundation of areas exposed during stage D.







sublittoral sediments onto islands developed on topographic highs (Fig. 27A).

Stage B: Complete inundation

Eventually, sublittoral environments covered North Dakota and all of the topographic highs (Fig. 27B) may have been submerged (Anderson, S. B., personal communication, 1982). Small carbonate buildups consisting of tabulate corals and rugosan corals, stromatoporoids, brachiopods, gastropods, and calcareous algae grew in this warm, shallow water. These buildups appear to have been restricted to the very shallow areas associated with the submerged topographic highs. This may be due to the fact that higher-energy conditions would have prevailed in these shallow areas, enhancing the growth of corals and other sessile benthonic organisms.

The organisms in these buildups are small in size compared to specimens in other similar faunal associations in Ordovician, Devonian, and Mississippian carbonates in the Williston Basin. This suggests that the organisms in the Interlake buildups died at an early age, were stunted adults, or were species of smaller-sized organisms. These possibilities indicate that the sea water chemistry may not have been ideal for the growth of these organisms (possibly slightly hypersaline?).

Stage C: Growth and progradation of littoral flats

The submerged topographic highs created shallower areas in the Interlake epeiric sea. As stated above, these submerged highs would have been areas of deposition of sediment carried by wind-driven waves and possibly currents. Once enough sediment

accumulated to break the water surface, islands could have developed (Fig. 27C). Continued accumulation of sediment on topographic highs resulted in progradation of island shorelines away from topographic highs in all directions; probably more so in the direction of the prevailing winds.

Stage D: Formation of calcretes and ferricretes

As progradation continued, the size of the islands became large enough so that even the highest storm waves could not reach their centers. These areas of subaerial exposure would continue to widen as progradation continued (Fig. 27D). Because no new sediment was brought into these areas, the carbonate material began to weather, forming calcretes and ferricretes. Of the cores sampled, core from NDGS 38 contains the best developed intra-formational paleosol (see appendix B). In this core, a 100-foot-thick ferricrete profile is developed on sublittoral and littoral flat complex rocks. When this weathered section is matched up with the gamma-ray log for NDGS 38, it corresponds to an anomalously strong deflection. A similar anomalous deflection exists in wells along and flanking the Nesson anticline (Fig. 28). This gamma-ray deflection is thickest along the crest of the Nesson anticline and thins away from it (Fig. 29). The abrupt thinning on the west and south of the Nesson anticline is caused by truncation along the Silurian-Devonian unconformity at the top of the Interlake. To the east of the Nesson anticline, the deflection thins and dies out well below the Silurian-Devonian unconformity. This thinning of the possible weathered zone east of the Nesson

Figure 28. Cross section showing location and correlation of the intraformational paleosol which is represented by an anomalous deflection in a gamma ray log. See text for discussion. All logs on cross section are gamma ray logs. Modified after Carlson and Eastwood (1962).

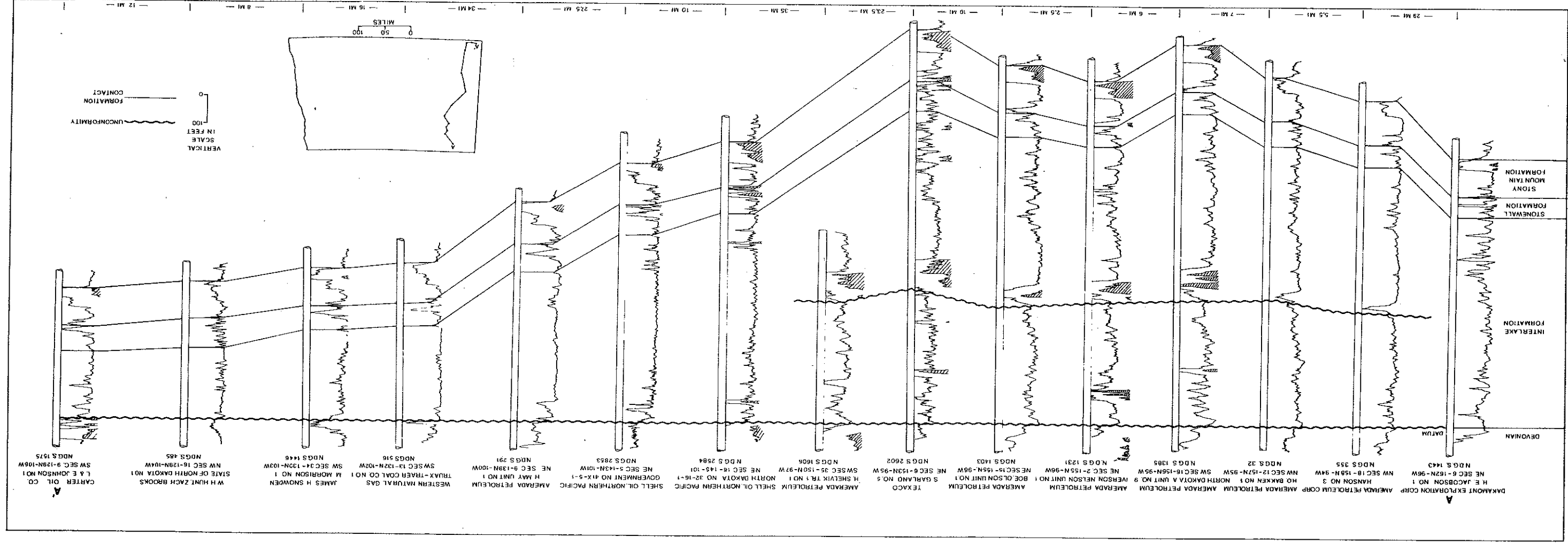
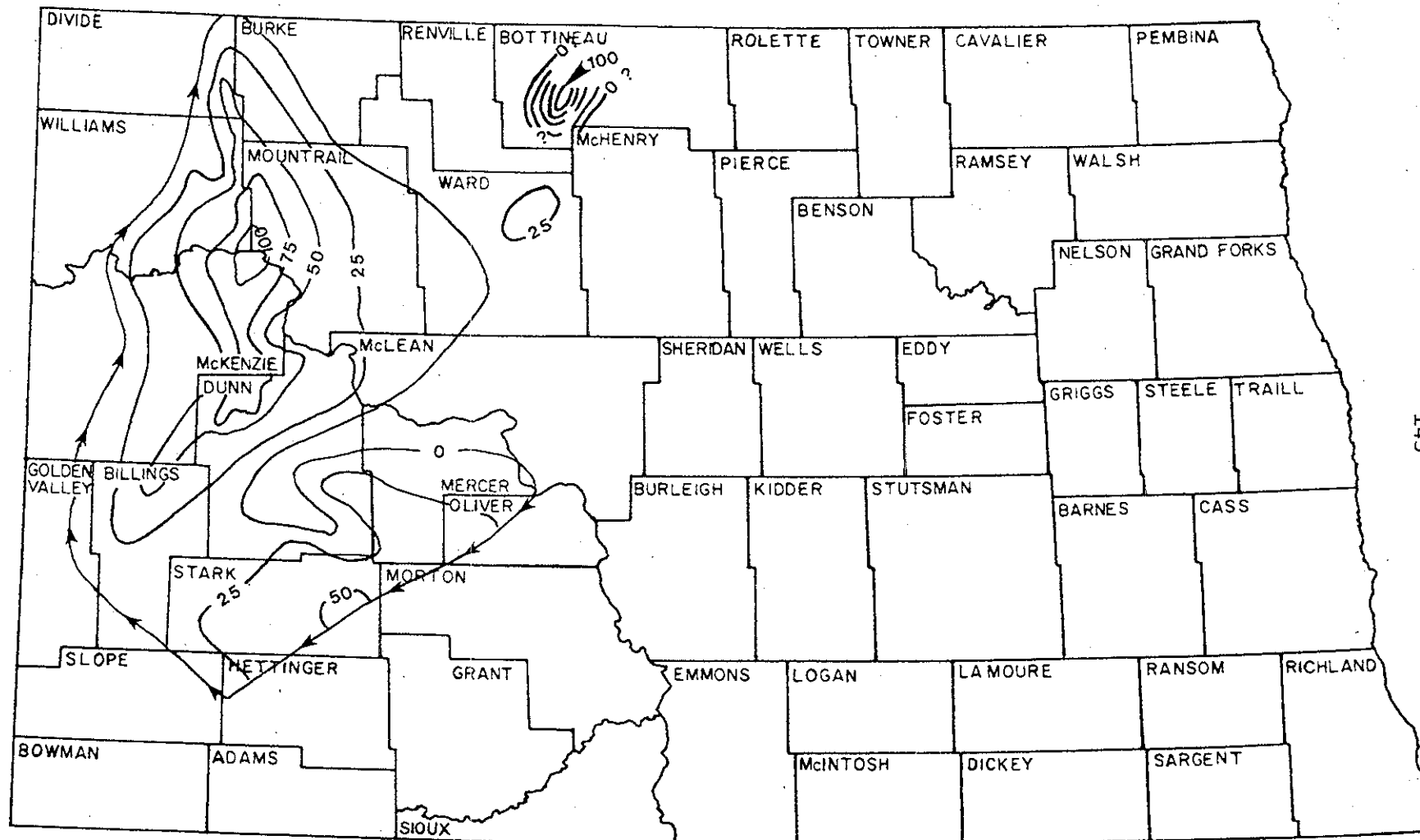
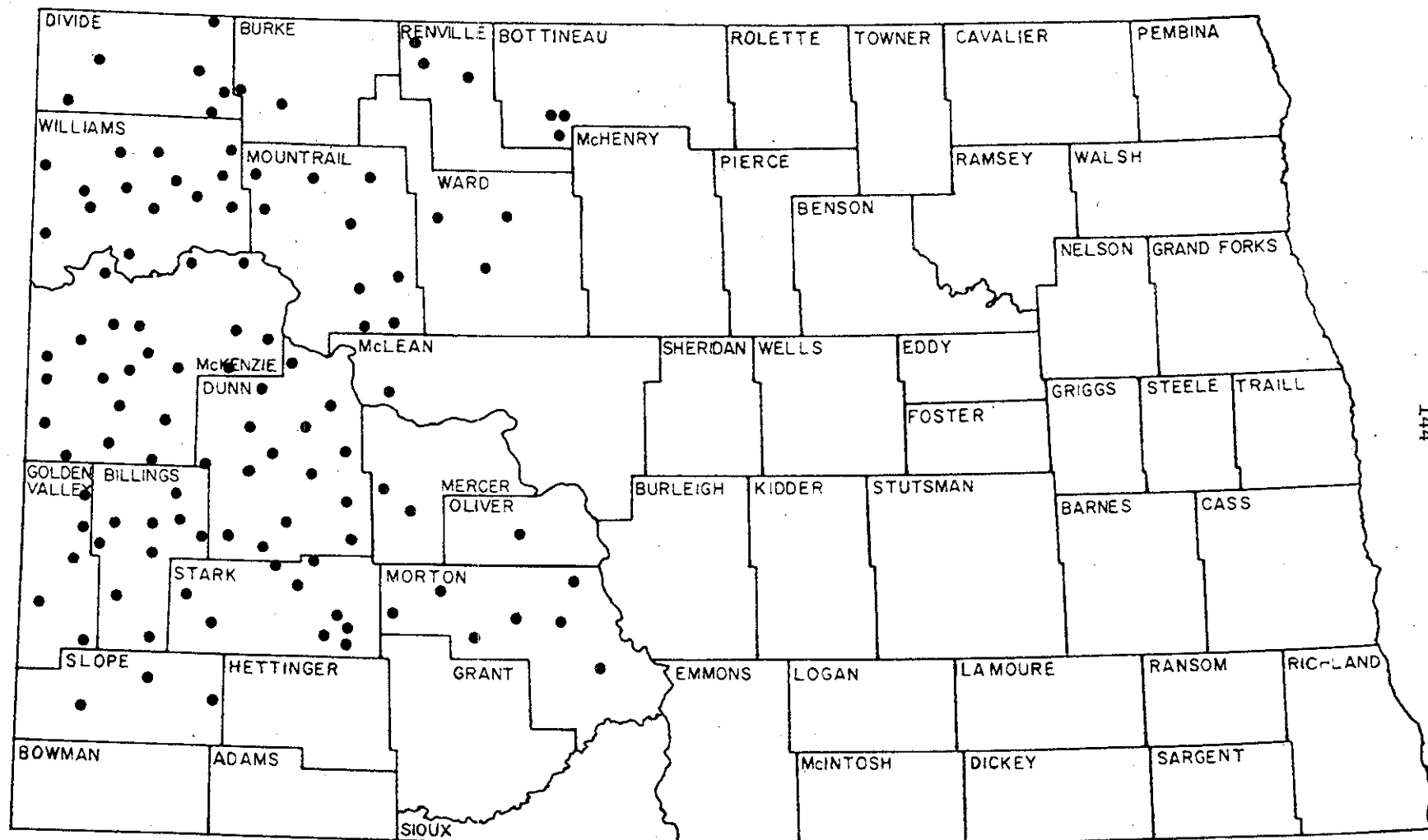


Figure 29. Areal extent of intraformation paleosol that developed on top of islands during stage D.

- A) Isopach map of the intraformational paleosol developed on topographic highs.
- B) Map showing the location of data points used for isopach map in Figure 29A.





anticline suggests that the entire study area may not have been exposed, and that weathering was restricted to topographic highs. Therefore, this intraformational unconformity was not basin-wide and probably marks the position of topographic highs during Interlake time.

Stage E: Onlap and reworking of calcretes and ferricretes

As in stage A, the position of the strandline rose resulting in onlap of sublittoral sediments onto topographic highs (Fig. 27E). This resulted in some reworking of soil developed during stage D. This relative rise in sea level ceased before the local highs were completely inundated, since no lithotypes indicative of sublittoral environments are present above the paleosols in cores from the "top" of the high area.

Stage F: Major regression and formation of basin-wide calcretes and ferricretes

At the close of Interlake time, a major regression resulted in complete withdrawal of the epeiric sea from the Williston Basin. This unconformity has regional extent and marks the top of the Tippecanoe Sequence (Sloss, 1963). Regression took place gradually, with high areas and basin periphery exposed first and the deeper parts of the basin exposed subsequently. The actual direction of regression is not clear since large amounts of material were lost during this extended period of erosion. In any case, littoral flat complexes gradually covered all previously sublittoral environments as the epeiric sea regressed (Fig. 23). Soil profiles developed behind the littoral flats and expanded as the sea regressed. Finally, the entire basin was exposed resulting

in formation of basin-wide calcretes and ferricretes (Fig. 27F).

Alternate Interpretations

LoBue (1982), in a smaller-scale version of this study, proposed a depositional history for the Interlake in western North Dakota somewhat similar to the one presented above. The major differences are that stage C above is called regression and stage D above is called a transgression. The use of the words transgression and regression may not be appropriate in this instance. Landward or seaward movement of the strandline can occur in transgressive, regressive or static sea level conditions (Vail et al., 1977). Therefore, local progradation and onlap should not be used as evidence for the direction of regional sea level movements. LoBue (1982) also stated that the Nesson anticline may have been emergent throughout Interlake time. Evidence collected subsequently suggests that this may not be true.

Magathan (1973) looked at the Interlake in the subsurface of Saskatchewan and studied the nature of the unconformity at the top of the Interlake. She suggested that as Interlake sediment was being exposed along the periphery of the Williston Basin during regression at the end of Interlake time, the sediment was slowly being reworked in a flood plain. This flood plain developed landward of the regressing Interlake epeiric sea and produced the upper Interlake Formation in Saskatchewan.

There was certainly some reworking of Interlake material during the long period of exposure during Late Silurian-Early Devonian time, but in North Dakota, the upper Interlake just below

the unconformity represents weathered littoral flat complex environments. It is possible that the northern part of the Interlake in Saskatchewan was closer to the margin of the epeiric sea than the North Dakota portion so that major recycling in flood plans took place in Saskatchewan, and not in North Dakota.

DIAGENESIS

Introduction

Diagenetic features in the Interlake Formation were produced by a complex series of processes that began in the environment of deposition and continued through deep burial. It is important to recognize the spatial and temporal relationship between these processes in order to understand the vertical and lateral distribution of diagenetic features.

Choquette and Pray (1970) suggested a classification scheme for major time stages in which diagenesis occurs. This scheme consists of five major diagenetic-time environments. These are: 1) predepositional, 2) depositional (penecontemporaneous), 3) eogenetic, 4) mesogenetic, and 5) telogenetic. Choquette and Pray (1970) applied these terms to porosity development; in this study, however, these terms will be expanded to include dolomitization and cementation events as well.

Only predepositional, depositional, eogenetic and mesogenetic are applicable to the Interlake. The predepositional stage begins when the sedimentary particle is formed and ends with its final deposition. Depositional diagenetic events occurred immediately after deposition. Diagenetic processes that took place during this time were those that were directly related to the environment of deposition. Eogenetic diagenetic events took place during early

burial of the sediment where diagenetic processes were also closely related to the surface (subaerial or subaqueous). Mesogenetic diagenetic events took place during deeper burial (Choquette and Pray, 1970, p. 215).

Dolomite, porosity, and cement, the most important diagenetic features in the Interlake, will be discussed in this time framework. Certain diagenetic features were interpreted in previous sections of this paper. These will be mentioned again in the following discussion for completeness.

Dolomite

The following discussion is limited to dolomite that is interpreted as replacement dolomite. Dolomite cement is discussed in the section of this paper on cementation. Replacement dolomite is found in almost every lithotype in the Interlake. The petrography and occurrence of the dolomite were the most important parameters used for paragenetic interpretations.

Microcrystalline dolomite is common in lithotypes which represent littoral flat complex environments. Peloids (which may have been fecal pellets) and gastropod shells are composed of dolomite, indicating that previously existing calcite and aragonite sediment was replaced.

On modern tidal flats, dolomitization of sediment is an early eogenetic (penecontemporaneous) diagenetic process. Dolomitized sediment and dolomitic crusts are common features on supratidal flats on Andros Island (Shinn et al., 1965) and on Bonaire (Deffeyes et al., 1965). On Bonaire, recent dolomite forms crusts

in supratidal areas which consist of 2 micron-long dolomite crystals in a pelleted lime sand and mud. Gastropod shells and pellets found in these modern dolomitized crusts are also composed of dolomite; this indicates that the dolomite has replaced previously existing calcite and aragonite sediment (Deffeyes et al., 1965, p. 74). On Andros Island, dolomite occurs only in supratidal areas; the highest percentages are within surface crusts that form by lithification of underlying sediment (Shinn et al., 1969, p. 224). Individual dolomite crystals are small (1 to 2 microns long) and are found within pellets, skeletal grains, and mud (Shinn et al., 1969, p. 225). Dolomite in dolomitized rocks of littoral flat origin in the Interlake is petrographically similar to dolomite in modern dolomitized tidal flat sediment. This suggests that Interlake rocks of littoral flat complex origin were dolomitized by penecontemporaneous diagenetic processes, similar to those active on modern tidal flats.

There are several models to explain penecontemporaneous dolomitization on tidal flats. These are seepage reflux (Adams and Rhodes, 1960), evaporative pumping (McKenzie et al., 1980), or capillary concentration (Shinn et al., 1965) of brines derived from sea water which pass through and dolomitize tidal flat sediment. With the available data, it is difficult to decide the applicability of any of these models to the Interlake Formation. However, certain theoretical aspects of Interlake littoral flat complexes may help to put some constraints on these dolomitization

models.

Littoral flat complexes on islands in the Interlake epeiric sea were possibly only inundated during wind-generated or storm-generated high water. Therefore, inundation of Interlake littoral flat complexes was probably not as regular as is inundation of modern tidal flats. If this was true, then sea water brought onto littoral flat complexes by storms or high winds would have had more time to evaporate and become hypersaline between wettings. This concentration of sea water could have also happened in littoral environments as well as in supralittoral environments; during periods of prolonged calm weather, the sediment in the littoral zone would not be influenced by vigorous wave action, allowing evaporation of sea water in the sediment. The mechanism of dolomitization of littoral flat complex sediment is probably similar to the model proposed by McKenzie et al. (1980, p. 27 and 28) for dolomitization of sediment on the sabkhas of Abu Dhabi, Persian Gulf. Sea water brought onto Interlake littoral flats by storm- or wind-generated high water partially evaporated to form brine. To increase the magnesium-to-calcium ratio in the brine, gypsum probably precipitated first, but was subsequently dissolved by influxes of sea water or meteoric water, and so was rarely preserved. The Mg^{++} -rich brines then sank into and dolomitized Interlake littoral flat sediment. Since the littoral flats were infrequently flooded (only during storm- or wind-generated high water) capillary evaporation of interstitial water within the sediment would have brought a continual supply of dolomitizing

fluids to the surface. The difference between penecontemporaneous dolomitization on Interlake littoral flat complexes and that on modern tidal flats is that dolomitization on Interlake littoral flats took place in both littoral and supralittoral environments; on modern tidal flats dolomitization is restricted to supratidal environments. Dolomitization of sediment on arid littoral flat complexes took place in the same manner (see discussion of anhydritic dolomitic mudstone lithotype).

Isolated dolomite rhombs in lithotypes which represent supralittoral pond sediment may have been penecontemporaneous in origin. Water in supralittoral ponds was probably hypersaline and could have dolomitized sediment accumulating within them in a process similar to the seepage reflux model of Adams and Rhodes (1960). These authors developed this model to explain the occurrence of dolomite in Permian rocks of west Texas. Their thesis was that water in back-reef lagoons underwent high amounts of evaporation which caused precipitation of gypsum, thus removing Ca^{++} from the water. The water, now rich in Mg^{++} , would have been denser than sea water which filled pore spaces in underlying carbonate sediment. Therefore, the heavy brines would have displaced the sea water and passed through the sediment, dolomitizing carbonate material.

Deffeyes et al. (1965, p. 81) also suggested that seepage reflux is now occurring beneath supratidal ponds on Bonaire. However, according to Longman (1981, p. 125) no example of modern-day seepage reflux dolomite has been found. Since evaporitic

conditions necessary for brine formation were probably more prevalent on Interlake littoral flats than on modern tidal flats, a more consistent flow of dolomitizing fluids would have been produced in pond sediment.

Rocks in the ooid grainstone lithotype are partially dolomitized and do not appear to have been subaerially exposed. Therefore, partial dolomitization of ooid grainstone rocks may have been an eogenetic event which took place after this material was buried and subjected to a mixed fresh and sea water environment. Mixing zone dolomitization (Badiozamani, 1973) occurs when the ratio of fresh water to sea water is about 5:1. This results in a fluid capable of dissolving calcite and precipitating dolomite. When the islands in the Interlake epeiric sea became large enough, a fresh water lens could have developed beneath them. This would have resulted in a subsurface mixing zone which would have migrated seaward as the islands became larger, intersecting buried ooid shoals.

Mixing zone dolomitization is a slow process; because areas where mixing of sea water and fresh water have existed for the past few thousand years do not contain dolomite (Longman, 1981, p. 129). The fact that the ooids in the ooid grainstone lithotype are only partially dolomitized and have well-preserved internal structure suggests that dolomitization was a slow "lit-par-lit" process. This may fit a mixing zone model.

Coarse-grained dolomite in pelmatozoan anthozoan wackestone and cryptalgal laminate rocks and dolomite associated with

stylolites and microstylolites probably represent the result of mesogenetic diagenetic events. The two most widely accepted models for the formation of mesogenetic dolomite are the pressure solution model of Wanless (1979) and the deep brine model of Mattes and Mountjoy (1980).

Wanless (1979) documented that deep burial dolomitization may be intimately related to pressure solution. The response of limestone to pressure solution depends on the presence of impurities, particularly Mg^{++} and clay particles. Wanless (1979, p. 439) identified three styles of pressure-solution response in Paleozoic limestones. These are sutured-seam solution, non-sutured seam solution, and non-seam solution. Sutured-seam solution, which produces stylolites and grain-contact sutures, occurs in limestones with very little clay or silt content. Non-sutured seam solution, which produces microstylolites and clay seams, occurs in limestones that contain large amounts of clay or silt. Non-seam solution results in thinning of a unit and occurs in clean limestones. All of these forms of pressure solution can produce fluids which can dolomitize carbonate rocks. The source of the Mg^{++} for dolomitization was the carbonate adjacent to the stylolite, local interstitial water, organic material, or penecontemporaneous dolomite (Wanless, 1979, p. 459).

The dolomite generated by pressure solution processes is generally associated with stylolites or microstylolites and may occur along solution seams; larger dolomite rhombs tend to be zoned (Wanless, 1979, p. 458). Pressure solution dolomite produced

in clean limestones forms "an intergrown mosaic in solution-thinned zones" (Wanless, 1979, p. 459). Wanless (1979, p. 445) interpreted nodular dolomitized rocks as products of solution along non-sutured seams (microstylolites).

Mattes and Mountjoy (1980) studied dolomite in the Miette buildup (Devonian) in the Front Range of the Rocky Mountains in Alberta. They concluded that the dolomite in the buildup was formed during five diagenetic stages, four of which were mesogenetic. Of these mesogenetic dolomites, only three are replacement dolomite. This dolomite is usually coarse grained and either partially or totally replaces the host carbonate.

Mattes and Mountjoy (1980, p. 293) concluded that a majority of the replacement dolomite formed by a combination of three processes: "(a) migration of brines from adjacent basin muds undergoing compaction, (b) pressure solution, (c) mixing of near-surface fluids with deep burial brines along fracture controlled conduits." The source of Mg^{++} for dolomitization by brines was formation fluids which derived the Mg^{++} from "connate sources, from adsorbed Mg^{++} derived during clay mineral transformations, and from structural Mg^{++} lost during the montmorillonite to illite transformation" (Mattes and Mountjoy, 1980, p. 292).

It is the opinion of the writer that mesogenetic dolomite in the Interlake Formation formed as a result of pressure solution dolomitization rather than deep brine dolomitization. Although dolomite produced by both mechanisms is petrographically similar

to mesogenetic dolomite in the Interlake, the intimate association of dolomite, stylolites and microstylolites in the Interlake supports the conclusion stated above. In addition, no "basinal" shale beds are associated with the Interlake; in general, fine-grained clastic material is lacking. Therefore, there was no source for the Mg^{++} (by dewatering of adjacent shales) for deep burial brines as suggested by Mattes and Mountjoy (1980). Rather, the source of the Mg^{++} was probably local material within the Interlake.

Several stages of pressure solution dolomitization are found in the Interlake. Thin, fine-grained zones of dolomite rhombs adjacent to stylolites and microstylolites may represent early stages, coarser-grained dolomite which replaces thick zones adjacent to stylolites may represent intermediate stages, and totally dolomitized rocks, which may be nodular, represent the extreme end result of these processes.

Not all rocks in the Interlake that have undergone pressure solution are dolomitized. Perhaps not enough local Mg^{++} was available for dolomitization of these rocks.

Porosity

Porosity in carbonate rocks is an important key to paragenetic interpretation because carbonate rocks and sediments and their porosities are sensitive to physiochemical events. An understanding of porosity development in carbonate rocks, both in the depositional environment and after burial, is valuable for interpreting both depositional and post-depositional events and for

solving the often complex diagenetic history of a carbonate rock (Choquette and Pray, 1970, p. 208).

Skeletal intraparticle porosity, present in small amounts in the pelmatozoan anthozoan wackestone lithotype, would have formed during the predepositional stage of porosity development as a result of chambers within individual skeletal organisms. Shelter porosity, also found in small amounts in the pelmatozoan anthozoan wackestone lithotype, and interparticle porosity, found in the ooid grainstone and peloidal quartz silt packestone lithotypes, would have formed during the depositional stage of porosity development. Shelter porosity formed as void spaces beneath skeletal debris on the sea bottom. Interparticle porosity formed as a result of the space that existed between grains as deposition occurred.

Fenestral porosity, which was discussed in previous sections, formed in high littoral and supralittoral environments during the primary eogenetic stage of porosity development. Moldic porosity formed during the secondary eogenetic stage when leaching of skeletal allochems occurred.

Vugular and pinpoint porosity formed during the secondary eogenetic stage when Interlake material was exposed to subaerial conditions. Formation of these porosity types was discussed previously in the section of paleosols. Only vugular and pinpoint porosities occur in amounts worth considering for petroleum exploration. These porosity types are best developed in calcretes associated with the unconformity at the top of the Interlake

Formation and perhaps with the intraformational unconformity located on top of structural elements in western North Dakota.

Fracture and intercrystalline porosity in the Interlake formed during the mesogenetic stage of porosity development. Intercrystalline porosity formed as a result of deep-burial dolomitization of Interlake rocks. Fracture porosity also probably formed after burial and lithification of Interlake rocks.

Cementation

Cementation in the Interlake Formation took place during eogenetic and mesogenetic diagenetic stages. Morphology of the cement was the best indicator of diagenetic environment in this study.

Early eogenetic cementation took place in sublittoral and littoral flat environments. In modern, low-energy, subtidal environments, sediments undergo little change. Movement of pore water, which is essential for cementation to occur, does not occur to any great degree. Therefore, when pore waters are stagnant, little cementation occurs (Longman, 1981, p. 96). In modern high-energy subtidal environments, early cementation is common (Longman, 1981, p. 94). Fibrous aragonite crusts are forming on allochems in Bahamian ooid shoals (Harris, 1979). In these shoals, radially-oriented fibrous aragonite cement forms isopachous rims around grains. James et al. (1976) studied early fibrous sub-sea cements in reefs off the coast of Belize and determined that this type of cementation is restricted to high-energy environments. They concluded that this restriction of cement to high-energy environments

was because these were areas where waves and swells impinged on the bottom, forcing water necessary for cementation through pore networks. On modern tidal flats, bladed carbonate cement is forming in supratidal and intertidal sediment (Shinn et al., 1965, p. 117, Bathurst, 1976, p. 369).

Folk (1974, p. 45) demonstrated that subsea and intertidal cements have a fibrous and bladed morphology due to the presence of Mg^{++} in pore water. Any carbonate cement that precipitates in sea water will have its sides selectively poisoned by Mg^{++} , resulting in a cement composed of short fibers rather than equant crystals. As the Mg^{++} content of the water decreases, calcite crystals will become bladed, then finally become equant when little Mg^{++} is left.

Therefore, fibrous carbonate cement is a product of high-energy marine phreatic (sublittoral) environments. Ooid grainstone is the only lithotype in the Interlake which formed in a high-energy sublittoral environment. Fibrous isopachous cement is common in this lithotype. This cement is petrographically similar to modern high-energy marine phreatic cement forming in Bahamian ooid shoals. Therefore, fibrous isopachous cement in the ooid grainstone lithotype probably formed during the early eogenetic state in high-energy sublittoral environments. Since aragonite is unstable (Bathurst, 1967, p. 231, 274), preservation of the fibrous habit of the cement suggests that it was composed of hi-Mg⁺⁺ calcite when it precipitated.

Bladed calcite cement in littoral flat complex lithotypes was an early eogenetic feature. This type of cement formed in fenestral porosity, and was commonly overlain by geopetal infill (see Fig. 9E) indicating that the cement formed prior to infill of the mud. These bladed cements, which formed a roughly isopachous rim in fenestral porosity, indicate that phreatic conditions existed where the Mg^{++} content of the water was less than that of sea water. Perhaps dolomitization of littoral flat complex sediment, which removed Mg^{++} from pore water, induced the formation of these bladed crystals. Although fenestral porosity formed in desiccating sediment, phreatic conditions may have existed when littoral flats were inundated by high water or beneath supratidal ponds.

Pendant or gravity cement, associated with paleosol horizons in the Interlake, formed during the eogenetic stage when Interlake material was subaerially exposed. Formation of pendant cement was discussed previously in the section on paleosols.

Equant calcite in the Interlake may have formed during several stages of diagenesis. Folk (1974, p. 47) stated that equant calcite cement can form in the near-surface zone just below the (meteoric) water table or in deeply buried environments. In shallow phreatic environments just below the water table, cementation is usually slow (due to lower ion concentration and slower rate of CO_2 outgassing) and Mg^{++} is present in relatively small amounts. Therefore, calcite cement crystals are large and equant. In deep-buried environments, there is a relative lack of Mg^{++} in

subsurface water due to selective capture of Mg^{++} at shallower depths. Most of the equant calcite cement in the Interlake is occluding primary porosity, such as fenestral porosity and interparticle porosity in rocks which were deposited on littoral flats. The fact that there is little evidence of compaction in these rocks suggests that cementation took place early in the eogenetic stage. Therefore, most of the equant calcite cement probably precipitated as littoral flat sediment was buried to depths below the meteoric water table (as the islands in the Interlake epeiric sea grew laterally, they could have developed fresh water lenses). The source of the Ca^{++} was probably overlying carbonate sediment which was dissolved by meteoric water or was Ca^{++} derived from sea water on the littoral flat complexes.

Baroque or saddle dolomite and equant dolomite cements in the Interlake probably formed during mesogenetic stages after deep burial of Interlake rocks. Radke and Mathis (1980) studied the formation and occurrence of saddle dolomite. Although they could not study fluid inclusions in saddle dolomite, fluid inclusions in contemporaneous minerals, such as calcite and fluorite, indicate temperatures of formation between 60 and 150 degrees Celsius (Radke and Mathis, 1980, p. 1160). Saddle dolomite is normally the only mesogenetic cement in dolostones while mesogenetic calcite predominates in limestones. This suggests that the source of the Mg^{++} for dolomite cementation is probably local (Radke and Mathis, 1980, p. 1160). In the Interlake Formation, saddle dolomite is restricted to dolostones from the deeper parts of

the Williston Basin (>11,500 ft.). This occurrence is similar to that predicted by Radke and Mathis (1980). Therefore, saddle dolomite in the Interlake probably formed after significant burial of dolomitic Interlake rocks in the mesogenetic stage when temperatures were approximately 100 degrees Celsius. Equant dolomite appears to be contemporaneous with saddle dolomite.

Small amounts of halite and anhydrite cement occlude secondary porosity (vugular, moldic, and fracture) in the Interlake Formation. Halite cement, which is found occluding vugular porosity in the paleosols, may be presumed to be mesogenetic because any halite precipitated in eogenetic and depositional stages would probably have been dissolved. As halite is found only in the upper portions of the Interlake its source may be overlying Devonian or Mississippian evaporite deposits. Anhydrite cement in moldic porosity (usually after gastropods in the peloidal quartz silt packstone lithotype) may have formed during the eogenetic stage when hypersaline brines from littoral flats percolated through underlying sediment causing dolomitization and precipitating anhydrite. Anhydrite cement, filling fracture porosity, was probably formed during the mesogenetic stage because it post dates the formation of fractures, which were mesogenetic features. Anhydrite-filled fractures were found only in one core (NDGS 207, Wells County). Since these fractures were found near the top of the Interlake, the source of anhydrite may be overlying evaporite horizons.

Severe Alteration and Brecciation

Severe alteration and brecciation of Interlake material occurred during the eogenetic stage when subaerial weathering formed calcretes and ferricretes. Formation of these paleosols was discussed in detail in the environmental interpretation section of this paper.

Replacement by Quartz

There are at least two silicification events recorded in the Interlake Formation. The first created chert nodules in carbonate sediment deposited in sublittoral environments. This replacement took place before dolomitization of the limestone (deep burial) because the chert nodules contain fossil material which was destroyed in surrounding dolomitized rock. The second event took place after precipitation of saddle dolomite cement, and thus was probably a mesogenetic event.

Knauth (1979) suggested that early chertification of limestone may take place in mixing zone environments just off shore from a carbonate shoreline. The first silicification event in the Interlake appears to have been early (perhaps eogenetic?) and may have taken place in the mixing zone as littoral flats prograded over sublittoral deposits.

PROBLEMS DESERVING FURTHER STUDY

Although many questions may have been answered by this study, there are still several problems that deserve further study.

The most important problem to be resolved is the establishment of time-stratigraphic data for the Interlake Formation. It is the belief of the writer that the gamma-ray log markers in the Interlake are not para-time markers as is believed by Porter and Fuller (1959). Because these markers do not represent geologically instantaneous events, e.g. volcanic ash falls, they may well be time-transgressive markers. The best time-stratigraphic data would be gained from a faunal study, and although diagenesis is severe, enough fossil data may exist to generate some time-stratigraphic data.

Dolomitization of Interlake rocks is another area deserving further study. Detailed geochemical study of the dolomite (microprobe data, cathodoluminescence data) may refine the dolomitization models proposed in this study.

Finally, detailed subsurface mapping of the Interlake, in North Dakota, such as that done by Brown (1978) in Montana, is needed to document further the effects of basement structures, such as lineaments, on the sedimentation patterns in the Interlake.

SUMMARY AND CONCLUSIONS

- 1) The Interlake Formation in the North Dakota part of the Williston Basin represents the deposits that formed on littoral flats and in adjacent high- and low-energy sublittoral environments in the epeiric sea that covered the Williston Basin during the Silurian Period.
- 2) The Interlake Formation contains a wide variety of lithologies which, for the purposes of this study, were divided into twelve lithotypes on the basis of textural similarities.
- 3) The Interlake Formation is characterized by extreme vertical and lateral variation of lithotypes. In general, the Interlake is muddier in the northeastern portions of North Dakota and is less muddy in the western portions of North Dakota.
- 4) Structurally controlled, topographic highs allowed the formation of islands in the epeiric sea. These islands contained environmental belts that were thinner and had steeper depositional slopes than larger, regional-scale environmental belts.
- 5) Lateral migration of environments within littoral flats and progradation of the flats away from topographic highs created the complex lithologic mosaic seen in the Interlake Formation.

6) The geologic history of the Interlake Formation is complex and represents dynamic interaction between changing positions of the strandline, topographic highs, and sedimentation. Progradation of littoral flats away from topographic highs resulted in widespread littoral flat deposition followed by formation of thick calcrete and ferricrete horizons on topographic highs. After a second, partial inundation of topographic highs, a major regression resulted in complete subaerial exposure of the Williston Basin, creating a second more extensive, calcrete and ferricrete horizon.

7) Most of the diagenesis in the Interlake occurred during eogenetic and mesogenetic diagenetic stages.

8) Dolomitization of sediment on littoral flats, formation of fenestral porosity, and precipitation of anhydrite in littoral flat sediment were important early eogenetic events.

9) Formation of paleosols and precipitation of equant calcite cement were important late eogenetic events.

10) Pressure solution dolomitization and precipitation of saddle dolomite cement were important mesogenetic events.

11) Only vugular and pinpoint porosities occur in amounts worth considering for petroleum exploration. These porosity types are best developed in calcretes associated with the unconformity at the top of the Interlake Formation.

APPENDICES

APPENDIX A

WELL LOCATIONS, LEGAL DESCRIPTIONS, KELLY
BUSHING ELEVATIONS AND PALEOSOL DATA USED
IN ISOPACH MAP OF PALEOSOL (FIG. 29)

Well information is arranged alphabetically by county and numerically by North Dakota Geological Survey well numbers within counties. Well locations are based on the standard Land Office Grid System. In the appendix heading, QTR stands for the first and second quarter of a section. SEC, T, and R stand for section, township (north), and range (west) respectively. Kelly Bushing (KB) elevations are in feet above sea level. Depths for the top and bottom of the paleosol are in feet below the Kelly Bushing. Thickness of the paleosol (in feet) was determined by calculating the difference between top and bottom depths of the paleosol horizon which is represented by a distinctly strong deflection on a gamma ray log.

BILLINGS

<u>Well No.</u>	<u>Qtr.</u>	<u>Sec-T-R</u>	<u>Operator Well Name</u>	<u>KB</u>	<u>Top</u>	<u>Paleosol Bottom</u>	<u>Thickness</u>
3268	NESW	10-139-101	Amerada Petroleum Corp. Scoria Unit #8	2540	-	-	0
5195	SENE	2-138-100	Lone Star Producing Alfred Schwartz "B"	2800	-	-	0
6470	C SWSW	15-142-98	Gulf Oil Corp. Schmidt #1	2708	12305	12325	20
6567	SESE	11-142-100	W.H. Hunt Trust Service Evonivk #1	2728	12218	12252	34
8075	NESE	8-142-101	Conoco, Inc. Federal Hanson 8 #1	2430	11550	11585	35
8079	C SESW	34-143-99	W.H. Hunt Trust Estate Demaniow #1	2747	12582	12625	43
8337	NESE	30-141-102	Patrick Petroleum Company Harris-Federal #1-30	2603	11330	11345	15
8391	NWSW	26-141-100	Supron Energy Corporation F-26-141-100 #2	2589	11745	11760	15
8558	NWSE	29-144-99	Amoco Production Company A.W. Thompson "B" #1-A	2675	12670	12736	66

BOTTINEAU

38	SWSE	31-160-81	The California Company Blanche Thompson No. 1	1526	6754	6857	103
4790	SESE	20-159-81	Union Oil Co of Calif. Abra Steen #1	1517	-	-	0
5071	NWSW	34-160-81	Estate of Wm. G. Hetis E. Van Horn et al #1	1503	6650	6665	15

<u>Well No.</u>	<u>Qtr.</u>	<u>Sec-T-R</u>	<u>Operator Well Name</u>	<u>KB</u>	<u>Top</u>	<u>Paleosol Bottom</u>	<u>Thickness</u>
<u>BURKE</u>							
5161	NESW	31-161-94	Phillips Petroleum Co. Holte- BND #1	2439	11220	11250	30
6802	SWNW	24-160-93	B.W.A. & B. Western Invest. Co. #24-12	2394	11450	11470	20
<u>DIVIDE</u>							
4837	SWNE	12-160-100	Miami Oil Prod. Inc. Roy Hagen #1	2112	12280	12330	50
5009	NESE	35-160-96	Consolidated Oil & Gas Co., Inc.	2290	11420	11458	38
5135	C NW	29-161-95	Charley Myer et al #1 Ashland Oil Inc.	2291	11290	11360	70
5248	NENE	10-160-98	F. Fenster #1-29 Oil Dev Co. of Texas	2243	-	-	0
5989	NESE	31-164-95	Rogers #1 W.A. Moncrief & Westhoma	1903	-	-	0
6673	NESW	30-160-102	Keba Oil & Gas #31-1 Hunt Trust Estate	2100	-	-	0
6751	NWNW	3-161-101	Nelson #1 Patrick Petro. Corp.	2244	-	-	0
6798	NESE	16-162-96	Johnson #1 Shell Oil Co. Rindel #43-16	2141	-	-	0

<u>Well No.</u>	<u>Qtr.</u>	<u>Sec-T-R</u>	<u>Operator Well Name</u>	<u>KB</u>	<u>Top</u>	<u>Paleosol Bottom</u>	<u>Thickness</u>
<u>DUNN</u>							
3044	C NENE	27-143-92	Amerada Petroleum Corp. Marie Selle T-1 #1	2200	11300	11340	40
5621	NENW	23-142-97	Mesa Petroleum Roshau #1	2583	12082	12098	16
6034	NWNW	32-145-97	Gulf Oil Corp. P. Marienko #1-32-1A	2518	12680	12698	18
6464	NWSE	19-147-95	Gas Prod Enterpr & Al Aquitaine BN #1	2526	13115	13165	50
6530	SENE	18-141-95	Amoco Prod. Co. Wolberg #1	2595	-	-	0
6582	NESW	8-148-95	Al-Aquitaine Oil & Gas Deep Creek	2378	13290	13375	85
6591	NWNW	35-143-94	Amoco Prod. Co. Odin Anderson #1	2130	-	-	0
6887		35-146-95	Amoco Prod. Co. Richardson #1	2324	-	-	0
7460	SWNW	4-144-93	Terra Resources, Inc. Nordsven #1-4	2240	12070	12080	10
7745	NENE	10-147-92	Santa Fe Energy Co. Young Bear #1	2048	12215	12240	25
7760	SESW	24-146-93	Mosbacher Pruet Oil Co. Thomas Cook #24-1	2318	-	-	0
7978	SWSE	17-145-91	Terra Resources, Inc. Tozier #1-17	2223	-	-	0

<u>Well No.</u>	<u>Qtr.</u>	<u>Sec-T-R</u>	<u>Operator Well Name</u>	<u>KB</u>	<u>Top</u>	<u>Paleosol Bottom</u>	<u>Thickness</u>
<u>DUNN (con't.)</u>							
8095	SWNW	17-149-93	Shell Oil Company	2330	13055	13110	55
8243	SESE	36-142-92	Packineau BIA #12-17 Houston Oil & Minerals Corporation	2147	-	-	0
8374	NENE	4-144-96	Union State #44-36 Adobe Oil & Gas Corp. Federal Killdeer #41-4	2435	12750	12770	20
<u>GOLDEN VALLEY</u>							
6563	NWNE	4-139-105	Shell Oil Co. Smith #31-4	2744	-	-	0
7094	NWNW	20-144-103	Gulf Oil Corp. Boyce Federal #1-20-1A	2422	-	-	0
7255	SWSE	3-142-103	Shell Oil Co. BN #34-3	2595	-	-	0
7842	SWSW	28-137-103	Bass Enterprises Prod. Co. Bullion Butte Federal #28-1	2728	-	-	0
8460	NWNE	31-141-103	Jake L. Hamon & Samson Resources Co. Tescher #3	2726	-	-	0

<u>Well No.</u>	<u>Qtr.</u>	<u>Sec-T-R</u>	<u>Operator Well Name</u>	<u>Paleosol</u>			
				<u>KB</u>	<u>Top</u>	<u>Bottom</u>	<u>Thickness</u>
<u>MCKENZIE</u>							
4723	SENE	23-151-101	Consolidated Oil & Gas Co., Inc. Federal Land Bank et al #23	2048	-	-	0
5655	C SW	25-150-104	Pennzoil Company Federal #25-1	2170	-	-	0
5840	NESE	26-150-104	Union Oil Co. of Calif. Federal #26-1	2103	-	-	0
6014	NENE	19-145-103	Terra Resources, Inc. BNRR	2590	-	-	0
6049	SESE	8-148-102	Kerr-McGee Corp. West Law #1	2446	-	-	0
6414	NENW	8-148-104	Shell Oil Co. US Govt. #21-8	2334	-	-	0
6616	NENW	26-153-101	Mosbacher Pruett Oil Co. FLB #1-26	2100	-	-	0
6826	NENW	19-149-97	Samedan Oil Corp. Kelly #1	2244	13190	13253	45
6959	SESW	30-145-99	Ladd Petr. Corp. Federal #30-24	2493	12490	12525	35
6984	NENE	10-147-101	Pennzoil Co. & Depco Federal #10-41	2217	-	-	0
7001	NWSW	34-154-95	Texaco Inc. & Amerada Red River Unit 1 #1	1895	11868	11972	104

<u>Well No.</u>	<u>Qtr.</u>	<u>Sec-T-R</u>	<u>Operator Well Name</u>	<u>KB</u>	<u>Top</u>	<u>Paleosol Bottom</u>	<u>Thickness</u>
<u>MCKENZIE (con't)</u>							
7233	NWSW	16-153-97	Getty Oil Co. Tobacco Garden #16-12	2052	13365	13450	85
7571	C SWNE	31-151-95	Texaco Inc. Reitsch NCT-2 #4	2486	12830	12900	70
7651	SENE	27-153-101	Hosbacher Pruet Oil Co. Herman Schmitz #27-1	2056	-	-	0
7673	SWSW	20-150-94	Helmerich & Payne, Inc. Matthew #1-20	2231	12900	12950	50
7685	SWSW	34-147-99	Pennzoil Co. Slawson #34-12 MC	2581	13150	13190	40
7845	SENW	23-150-101	Petroleum Inc. & Excel Nygaard State #1	2318	-	-	0
8020	SWNE	34-150-99	Alpar Resources, Inc. Rogness #1-34	2114	13050	13078	28
8193	SENW	3-146-102	Pennzoil Company & Depco Covered Bridge #3-22	2185	-	-	0
8287	C NWSE	18-146-104	Shell Oil Company USA #33-18-123	2450	-	-	0
8314	SENE	8-147-103	Shell Oil Company USA #42-8	2221	-	-	0
8322	SWSE	34-151-102	HNG Oil Company Link #34-1	2267	-	-	0
8399	NENW	29-150-101	Texas Gas Exploration Corp. Nygaard #1-29	2320	-	-	0
8471	NENW	22-149-96	Apache Corporation Federal #22-1	2408	13200	13285	85

<u>Well No.</u>	<u>Qtr.</u>	<u>Sec-T-R</u>	<u>Operator Well Name</u>	<u>KB</u>	<u>Top</u>	<u>Paleosol Bottom</u>	<u>Thickness</u>
<u>MCLEAN</u>							
8060	C SWNE	7-148-89	Apache Corp. Solcum #1	2109	-	-	0
<u>MERCER</u>							
6683		13-143-90	True Oil Co. Hauck #13-13	2097	-	-	0
7616	C SWNW	29-144-90	Conoco Inc. Entze 29 #1	2219	-	-	0
<u>MORTON</u>							
1620	NESW	27-139-90	Pan American Pet. Corp. Raymond Yetter #1	2426	-	-	0
5979	NWNW	18-136-81	Houston Oil & Mineral John J. Haider #1	1901	-	-	0
7340	C NWSE	26-140-88	Amoco Prod. Co. Richter #1	2230	-	-	0
7770	C NWSW	6-138-85	Amoco Prod. Co. Karch #1	2076	-	-	0
8395	SWSE	1-137-87	Sun Oil Company Jacob Larson #1	2211	-	-	0
8553	SENW	17-140-82	Shell Oil Company Vogel #22-27	1994	-	-	0

<u>Well No.</u>	<u>Qtr.</u>	<u>Sec-T-R</u>	<u>Operator Well Name</u>	<u>KB</u>	<u>Top</u>	<u>Paleosol Bottom</u>	<u>Thickness</u>
<u>MORTON (con't)</u>							
8630	SESW	2-134-83	Pennzoil Company Railroad Bend #2-24	2146	-	-	0
<u>MOUNTRAIL</u>							
4386	SESE	28-151-90	Empire State Oil Co. Vorwerk #1	2216	12020	12039	19
6087	SWSE	9-157-94	Tom Brown Inc. Jorstad #9-34	2325	11985	12058	73
6289	C NESW	10-155-91	Thomson Petr. Inc. Harstad et al #1	2281	12055	12100	45
6677		14-157-90	True Oil Co. Halverson #33-14	2305	11245	11255	0
6780	SENE	24-151-89	Bass Enterpr. Prod. Co. Robert Andes #24-1	2133	11215	11235	20
6872		16-153-88	Marathon Oil Co. Mae Olson #1	2108	10892	10910	18
7741	SWSW	28-156-94	Kissinger Petr. Corp. Ortloff #13-28	2331	13005	13080	75
8071	NENW	3-152-90	Lear Petroleum Exploration, Inc.	1967	11501	11518	17
8371	SWSW	17-157-91	Parshall, S.D. #1 True Oil Company Kuster #14-17	2310	11895	11920	25

<u>Well</u> <u>No.</u>	<u>Qtr.</u>	<u>Sec-T-R</u>	<u>Operator</u> <u>Well Name</u>	<u>KB</u>	<u>Top</u>	<u>Paleosol</u> <u>Bottom</u>	<u>Thickness</u>
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OLIVER

4940	SESW	24-142-85	General American Oil Co. of Texas Raymond Henke #1-24	2252	8780	8788	8
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RENVILLE

6401	NESW	10-163-87	Shell Oil Co. Wisdaht #23-10	1703	-	-	0
6504	SWNE	1-162-87	Great Yellowstone Ones #1	1716	-	-	0
7577	C SWNW	15-160-86	Shell Oil Co. Dewing #12-15	1842	-	-	0

SLOPE

4241	NESW	23-136-101	H.L. Hunt NPRR "A" #3	2868	-	-	0
4280	NESW	18-135-103	Amerada Petr. Corp. Ivan Mitchell #1	2971	-	-	0
7987	NWSE	17-135-98	Cities Service Co. Schmitt B-1	2870	-	-	0

<u>Well</u> <u>No.</u>	<u>Qtr.</u>	<u>Sec-T-R</u>	<u>Operator</u> <u>Well Name</u>	<u>KB</u>	<u>Top</u>	<u>Paleosol</u> <u>Bottom</u>	<u>Thickness</u>
<u>STARK</u>							
6797	SESW	16-139-92	W.H. Hunt Trust Estate Rummel-State #1	2494	10400	10460	60
6812	NWNW	1-138-93	W.H. Hunt Trust Estate Elkins #1	2479	-	-	0
7007	C SESE	26-138-98	Supron Energy Corp. Privratsky #1	2756	11020	11050	30
7247	C NESW	5-140-95	Hunt Energy Corp. Barta #1	2455	11400	11430	30
8088	C NWNE	28-141-93	Mobil Oil Corporation William Bernhardt #1	2165	-	-	0
8098	C SENE	9-139-99	Monsanta Co. Froelich #1	2611	11555	11570	15
8169	C NENW	21-138-92	Gulf Oil Corp. Leviathan #1-21-1B	2372	-	-	0
8342	NWNW	36-140-95	Supron Energy Corporation Lawrence #1	2418	11128	1158	30
<u>WARD</u>							
105	SWNE	2-153-85	Stanalind Walter & Ingeberg Waswick #1	2175	-	-	0
4990	NWSW	22-156-84	The Anschutz Corp. Richard Musch #1	1788	8490	8532	42
7612	SESW	15-155-87	Marathon Oil Co. Berg #15-24	2219	-	-	0

<u>Well No.</u>	<u>Qtr.</u>	<u>Sec-T-R</u>	<u>Operator Well Name</u>	<u>KB</u>	<u>Top</u>	<u>Paleosol Bottom</u>	<u>Thickness</u>
<u>WILLIAMS</u>							
4510	SWNE	7-154-103	Lamar Hunt	2268	-	-	0
5114	SENW	21-158-103	Bank of N.D. Oyloe #1	2192	-	-	0
5197	NENW	9-157-95	Universal Resources	2434	11910	11950	40
6362	C SW	18-155-95	Agnes Burns #1	2305	12030	12100	70
6702	C NWSW	30-157-101	Amerada Petroleum Corp.	2383	-	-	0
6896	NESE	22-157-100	Hemsing #1-9	2075	-	-	0
6915	SWSW	26-156-95	Amerada Hess Corp.	2411	12640	12720	80
7054	C NENW	14-156-102	Marvin Iverson #23-18	2151	11965	11995	30
7063	C SWNW	22-157-97	Union Texas Petro.	2339	12825	12860	35
7330	NENE	33-159-100	Melvin Anderson #1	2011	-	-	0
7405	SWNE	8-155-99	W.H. Hunt Trust Estate	2116	-	-	0
7595	C SESE	15-158-95	Njos #1	2505	11920	11970	50
			Kissinger Petro. Corp.				
			Olson #13-26				
			Patrick Petro. Co.				
			Fedje #1				
			Hunt Energy Corp.				
			Johnson #1				
			W.H. Hunt Trust Est.				
			Dragseth #1				
			Al-Aquitaine Explor Ltd.				
			Brown #1-8				
			Energetics, Inc.				
			Hove #44-15				

<u>Well No.</u>	<u>Qtr.</u>	<u>Sec-T-R</u>	<u>Operator Well Name</u>	<u>KB</u>	<u>Top</u>	<u>Bottom</u>	<u>Thickness</u>
<u>WILLIAMS (con't)</u>							
7692	SWSE	24-155-102	Depco, Inc. Mortenson #34-24	2192	-	-	0
7712	SWSW	21-155-98	Shell Oil Co. Kirkpatrick #14-21	2249	13330	13365	35
8239	C SWNE	17-158-97	Lear Petroleum Exploration, Inc. Oase #1	2298	-	-	0
8413	SENE	14-156-97	Depco. Inc. Wittrock #22-14	2255	12425	12478	53
8441	NENE	1-153-100	Mapco Production Company Tofte #1-1	2313	13215	13260	45

APPENDIX B

CORE AND THIN SECTION DESCRIPTIONS

Cores and thin sections are arranged alphabetically by county and by North Dakota Geological Survey (NDGS) well numbers within counties. Core and thin section depths were recorded from core-box labels as filed with the NDGS Wilson M. Laird core and Sample Library. Core descriptions are given in intervals listed on the left side of the page. Thin section descriptions are indented, and are listed by NDGS well number and depth below the Kelly Bushing. Each core description is preceded by a legal description which includes well number (NDGS), location (section, township, and range), operator, and well name. The top of the Interlake and Stone-wall Formations, cored interval, and Kelly Bushing (KB) elevations (in feet above sea level) are also included with the legal descriptions.

Description format is as follows: Rock name, allochems (listed in order of decreasing abundance); color; mineralogy; porosity, open/closed; cement; sedimentary structures (if any); other diagenetic features (dolomitization, neomorphism); and miscellaneous features.

Dunham's (1962) classification was used except in cases where all depositional features were obliterated by diagenetic features; in these cases the terms dolostone or limestone were used.

BOTTINEAU COUNTY

NDGS # 38

Location-Sec. 31-160N-81W

Company- The California Company

Well Name- Blanche Thompson No. 1

Formation Tops- Interlake Formation- 6582

Stonewall Formation- 7100

Cored Interval- 6582-7015

KB-1562

6582-6583	Wackestone, intraclasts; red and gray; dolomite.
6583-6586	Mudstone; gray; dolomite; nodular
6586-6589	Wackepackstone, intraclasts; gray; dolomite.
6589-6592	Mudstone; gray; dolomite; large vugular porosity, spar calcite cement, laminated micrite infill.
6592-6595	Mudstone, intraclast horizons; gray; dolomite; small vugular porosity, open.
6595-6600	Mudstone; red, tan and pink mottled; dolomite.
6600-6601	Wackestone, intraclasts, peloids; gray; dolomite.
6601-6604	Mudstone; gray; dolomite; large vugular porosity, open; salt cube casts (?).
6604-6609	Mudstone; gray; dolomite; slightly laminated.
6609-6614	Mudstone, peloids; gray; dolomite; fenestral porosity, open.
6614-6632	Mudstone, intraclasts; pink; dolomite; some laminations.
6632-6634	Wackestone, peloids; gray; dolomite.
6634-6636	Missing
6636-6638	Wackestone, peloids; gray; dolomite.
6638-6640	Mudstone; gray; dolomite; vugular porosity, open.

- 6640-6643 Wackestone, peloids; gray; dolomite; laminated.
- 6643-6644 Wackestone, intraclasts, peloids; gray; dolomite.
- 6644-6670 Wackestone, peloids; pink and tan; dolomite.
- 6670-6673 Mudstone, peloids; tan; dolomite.
- 6673-6691 Wackepackstone, peloids; tan; dolomite; vugular porosity, open.
- 6691-6693 Packstone, peloids; gray; dolomite.
- 6693-6697 Mudstone; tan; dolomite; vugular porosity, open.
- 6697-6701 Wackestone, peloids; tan; dolomite.
- 6701-6702 Mudstone; tan; dolomite; vugular porosity, open.
- 6702-6748 Mudstone, peloids; pink; dolomite; vugular porosity partially filled with micrite.
- 38-6715 Wackestone, peloids; tan; dolomite; fenestral and intracrystal porosity, open.
- 38-6721 Packstone, peloids; white; dolomitic calcite.
- 6748-6749 Wackestone, peloids; pink; dolomite.
- 6749-6754 Mudstone, intraclasts; pink to gray; dolomite; cracks filled with dolomitic mudstone.
- 38-6749 Wackestone, peloids; tan; dolomite; fenestral porosity, closed; crystalline dolomite cement, wispy laminations.
- 6754-6757 Wackestone, intraclasts; pink; dolomite; clasts are reworked ferruginous dolostone.
- 6757-6817 Ferruginous dolostone; red; calcite, dolomite, and ferruginous calcite; thin zones of fossiliferous dolostone.
- 38-6758 Ferruginous dolostone, ferruginous concretions, red; calcite and ferruginous calcite; interparticle porosity, closed, pendant and blocky calcite cement.
- 38-6774 same as 6758

- 38-6777 Mudstone; red; dolomite; fracture and vug porosity, closed; crystalline dolomite cement.
- 38-6805 same as 6758
- 38-6813 Wackestone, pelmatozoans, brachiopods; tan; calcite; vugular porosity, closed; spar calcite cement, pendant cement; shell replacement; neomorphic spar; small dolomite rhombs.
- 6817-6820 Intercalated mudstone and wackestone, peloids; red; calcite.
- 6820-6829 Packstone, stromatoporoids, brachiopods, rugosan corals; tan; calcite.
- 38-6825 Wackestone, pelmatozoans, brachiopods, gastropods, intraclasts; tan; calcite; shell replacement; neomorphic spar, stylolites.
- 6829-6832 Mudstone; red and yellow; dolomite; nodular.
- 38-6830 Nodularized crystalline dolostone; red/orange; ferruginous calcite between nodules.
- 38-6830½ Nodularized crystalline dolostone; calcite cement; stylolites.
- 38-6831 Same as 6830½, ferruginous calcite.
- 38-6831½ Mudstone intraclasts, peloids; tan; dolomite; laminated (stromatolite?); fracture porosity, closed; numerous small tubules may be algal filaments.
- 6832-6836 Mudstone, intraclasts; tan; dolomite.
- 6836-6857 Ferruginous dolostone; red; calcite and ferruginous calcite; patches of tan dolostone.
- 38-6852 Crystalline dolostone; white.
- 6857-6859 Packstone, stromatoporoids, rugosan and tabulate corals; tan; calcite.

- 38-6858 Wackestone, brachiopods, pelmatozoans, bulbous stromatoporoids, gastropods, rugose and tabulate corals, trilobites, intraclasts; tan; calcite; intercrystal porosity, open; syntaxial cement; neomorphic spar; shell replacement; stylolites.
- 6859-6870 Mudstone; red, yellow and tan; dolomite; laminated and nodular.
- 38-6859 Crystalline dolostone; partially nodularized; dolomite cement; stylolites
- 38-6860 Crystalline dolostone; white; nodular; green dolomitic mud (?) between nodules.
- 38-6862 Crystalline dolostone; white; nodular.
- 38-6868 Mudstone; white; dolomite; nodular; crystalline and baroque dolomite cement.
- 6879-6882 Mudstone; tan; dolomite; mottled; vugular porosity, open.
- 6882-6885 Wackestone, intraclasts; tan; calcite; breccia zone (?).
- 6885-6890 Mudstone, tabulate corals; tan; calcite; large vugular porosity, partially closed; anhydrite and dolomite cement.
- 6890-6894 Packstone, intraclasts; pink; dolomite.
- 38-6893 Crystalline dolostone; pink; intercrystal porosity, open.
- 6894-6907 Mudstone; tan; dolomite; faintly laminated.
- 38-6899 Crystalline dolostone; tan; nodular; brown/green clay (?) between nodules.
- 38-6806 Wackestone, pelmatozoans, unidentified fossils, intraclasts, peloids; tan; dolomite; intercrystalline porosity, partially closed, dolomite cement.
- 6907-6908 Mudstone, pelmatozoans; tan, dolomite.
- 6908-6909 Packstone, intraclasts; tan; dolomite; (breccia zone).

- 6909-6910 Mudstone; tan; dolomite; thin bedded and laminated.
- 6910-6914 Stromatolites; flat and hemispherical; tan; dolomite.
- 6914-6925 Crystalline dolostone; tan.
- 38-6919 Crystalline dolostone; tan; inter-crystalline porosity, open; altered rugose corals and pelmatozoans (?).
- 6925-6929 Mudstone; tan; dolomite; laminated.
- 6929-6936 Mudstone; tan; dolomite.
- 6936-6938 Stromatolites, large hemispherical; tan; dolomite.
- 6938-6939 Mudstone; tan; dolomite.
- 6939-6941 Stromatolites, hemispherical; tan; dolomite.
- 38-6940 SH Stromatolite; peloids; tan; dolomite; fenestral and vugular porosity, partially open; wavy laminations; crystalline dolomite cement.
- 6941-6942 Packstone, intraclasts; tan; dolomite.
- 6942-6943 Mudstone, peloids; tan; dolomite.
- 6943-6947 Mudstone; tan; dolomite; laminated and non-laminated.
- 6947-6948 Stromatolites, laminar; tan; dolomite.
- 6948-6949 Wackestone, intraclasts; tan; dolomite; clasts are laminated; (breccia).
- 6949-6951 Mudstone; tan; dolomite; burrows.
- 38-6950 Mudstone; tan; dolomite; fracture and burrow porosity, partially closed; flat laminations; stylolites.
- 6951-6954 Mudstone; tan; dolomite.
- 6954-6956 Wackestone, intraclasts; tan; dolomite; (breccia).

- 38-6955 Wackepackstone, peloids, quartz silt;
tan; dolomite; stylolites.
- 6956-6959 Stromatolites; flat and LLH; tan; dolomite.
- 38-6958 Stromatolites, peloids; tan; dolomite;
wispy laminations.
- 6959-6970 Mudstone; tan; dolomite; laminated.
- 38-6861 Crystalline dolostone; light yellow;
nodular; baroque and crystalline
dolomite cement.
- 38-6969 Mudstone; tan; dolomite.
- 6970-6971 Wackestone, peloids; tan; dolomite.
- 6971-6973 Mudstone; tan; dolomite.
- 6973-6974 Stromatolites, flat; tan; dolomite; also some
mud chips.
- 6974-6977 Wackepackstone, intraclasts, skeletal grains;
tan; dolomite.
- 38-6976½ Wackepackstone, intraclasts, pelmatozoans,
brachiopods, gastropods, cephalopods,
trilobites; tan; calcite; abraded fossils;
imbricate fossils; shell replacement;
stylolites.
- 6977-6978 Mudstone; tan; dolomite; laminated.
- 6978-6980 Wackepackstone, intraclasts, brachiopods;
tan; calcite; imbricate fossils.
- 38-6979 Wackepackstone, intraclasts, brachiopods,
pelmatozoans, trilobites, gastropods, cephalopods, green algae (codiacian ?) tan;
calcite; shelter, intercrystal and fracture
porosity, closed and partially closed;
baroque dolomite and calcite spar cement;
abraded and imbricate allochems; large
dolomite rhombs; anhydrite replacement;
dolomite rhombs in intraclasts and concentrated along stylolites; neomorphic spar;
shell replacement.

- 6980-6993 Mudstone; tan; dolomite.
- 38-6993 Crystalline dolostone; tan.
- 6993-6996 Wackestone, flat chips; tan; dolomite; breccia;
some laminated dolomite with scour
surface.
- 38-6994 Packstone, intraclasts; tan; dolomite;
interparticle porosity, closed; breccia;
clasts composed of peloidal, intraclastic
packstone; material between clasts is
green/brown dolomitic mud.
- 6996-6999 Mudstone; tan; dolomite.
- 6999-7002 Wackestone, flat chips, oolites; tan; dolomite.
- 38-7000 Wackestone, flat chips, oolites, peloids;
tan; dolomite; moldic porosity, partially
closed; oolites have radial-fibrous
structure.
- 7002-7004 Wackestone, brachiopods; tan; dolomite;
imbricate allochems.
- 38-7003 Wackestone, brachiopods, peloids; light
brown; dolomite; interparticle porosity,
partially closed; imbricate allochems;
compaction.
- 38-7003½ Same as 7003.
- 7004-7006 Mudstone; gray; dolomite; laminated.
- 7006-7011 Mudstone, intraclasts; gray; dolomite; some
laminations.
- 38-7010 Mudstone, quartz silt; gray/green; dolomite;
burrows (?); extensive stylolitization.

CAVALIER COUNTY

NDGS #27

Location-Sec. 28-159N-63W

Company- Union Oil Company
of California

Well Name- Skjervheim No. 1

Formation Tops- Interlake Formation- 2310

Stonewall Formation- 2435

Cored Interval- 2310-2435 KB- 1562

- 2310-2363 Ferruginous mudstone, ferruginous concretions;
red; dolomite; some patches of weathered
dolostone.
- 27-2312 Ferruginous mudstone, ferruginous concretions;
red, dolomite and iron oxides; interparticle
porosity, closed; dolomite cement.
- 27-2337 Ferruginous mudstone; red; iron oxides;
small 1-2 micron red clots.
- 2363-2370 Breccia, intraclasts; tan; dolomite; clasts
are angular and upright, contain laminations
(algal).
- 27-2366 Breccia, intraclasts; medium gray; dolomitic
calcite; clasts are laminated (algal) and
contain open fenestral pores.
- 2370-2376 Mudstone; purple; dolomite; with 1 mm white
dots.
- 2376-2389 Stromatolites, flat; tan; dolomite.
- 27-2377 Stromatolite, flat; tan; dolomite/calcite;
complete and wispy laminations; calcite
and dolomite and interlaminated.
- 2389-2391 Mudstone; purple; dolomite; with 1 mm white
dots.
- 2391-2402 Mudstone; gray; dolomite; nodular.
- 27-2397 Crystalline dolostone; tan.
- 2402-2403 Wackestone, gastropods; gray; dolomite; faint
bedding.

- 2403-2406 Wackestone, rugose corals, brachiopods; tan; dolomite; nodular.
- 27-2403 Wackestone, pelmatozoans; tan; dolomite; stylolites.
- 27-2405 Wackestone, brachiopods, pelmatozoans, rugose corals; beige; dolomite; inter-crystal and vugular porosity, partially open; stylolites.
- 2406-2412 Mudstone; gray; dolomite; "lithographic".
- 2412-2414 Stromatolite; gray; dolomite; laminated; fenestral porosity, open; (one large hemispherical stromatolite).
- 2414-2416 Wackepackstone, intraclasts, unidentified fossils; tan; dolomite; clasts are laminated (algal).
- 27-2414 Wackestone, intraclasts, peloids, oolites (?); tan; dolomitic calcite; moldic porosity, partially open; clasts are laminated (algal) with small tubules penetrating laminae.
- 2416-2418 Mudstone; tan; dolomite; laminated.
- 27-2417 Wackestone, intraclasts, gastropods, green algae (?); unidentified; neomorphic micro-spar.
- 2418-2420 Mudstone; tan; dolomite; burrowed.
- 2420-2427 Mudstone; purple; dolomite; with 1 mm white dots.
- 27-2426 Mudstone; purple; dolomite; wispy and flat laminations; small, white, slightly calcitic dots.
- 2427-2430 Mudstone; tan; dolomite.
- 2430-2432 Packstone/grainstone, intraclasts; tan; dolomite; clasts are imbricate.
- 27-2431 Grainstone, oolites, peloids, intraclasts, grapestones; tan; dolomitic calcite; intra-particle and moldic porosity, open; isopachus cement.
- 2431-2435 Mudstone; tan; dolomite; burrowed.

NDGS #31

Location- Sec. 32-160N-63W

Company- Union Oil Company
of California

Well Name- Lillian Wohletz No. 1

Formation Tops- Interlake Formation- 1901

Stonewall Formation- 2068 (?)

Cored Interval- 1091-1991 KB- 1612

- | | |
|-----------------------|--|
| 1901-1909 | Ferruginous mudstone; red; iron oxides, dolomite; some patches of weathered dolostone. |
| 1909-1914 | Breccia, clasts; red; dolomite; clasts laminated. |
| 1914-1919 | Stromatolites, flat and hemispherical; tan; dolomite. |
| 1919-1920 | Mudstone; purple; dolomite; purple liesegang (?) bands (concentric). |
| 1920-1925 | Mudstone; red and yellow; dolomite; thin "stringers". |
| 31-1922 | Mudstone; yellow; dolomite; laminated (algal?). |
| 1925-1925 | Stromatolites, flat; tan; dolomite. |
| 1926-1938 | Ferruginous mudstone; red; iron oxides, dolomite. |
| 1938-1946 | Stromatolites, flat; tan; dolomite. |
| 1946-1949 | Mudstone; purple; dolomite; with 1 mm white dots. |
| 1949-1955 | Packstone/grainstone, oolites, pisolites, peloids; tan; dolomite; moldic and inter-crystalline porosity, open. |
| 31-1950A,B | Packstone, oolites; tan and white; dolomite; moldic porosity, open; oolites are squashed. |
| 31-1951
31-1953A,B | Packstone/grainstone, oolites, intraclasts, grapestones, brachiopods; tan; dolomitic calcite; interparticle and moldic porosity, partially open, isopachus cement. |

- 31-1954A,B Grainstone/packstone, oolites, grapestones, intraclasts, brachiopods; tan; dolomitic calcite; interparticle, moldic, and intercrystal porosity, partially open; spar calcite and isopachus cement.
- 1955-1959 Wackestone, peloids; tan; dolomite.
- 31-1955 Wackepackstone, peloids, intraclasts, brachiopods; medium brown; dolomitic calcite; intercrystal porosity, partially open; calcite spar cement.
- 1959-1965 Wackestone, stromatoporoids, tabulate and rugosan corals, cephalopods; gray and tan; dolomitic calcite; nodular; pyrite cube casts.
- 31-1959 Boundstone, stromatoporoids, brachiopods; tan; dolomitic calcite; growth-framework porosity, open.
- 31-1964 Boundstone, stromatoporoids, bulbous; tan; calcite/dolomite; growth-framework porosity, closed; spar calcite cement.
- 1965-1968 Mudstone; purple; dolomite; with 1 mm white dots.
- 1968-1971 Stromatolites, flat and hemispherical; tan; dolomite.
- 1971-1976 Grainstone/packstone, oolites, grapestones; tan; dolomitic calcite.
- 31-1971
31-1972A,B
31-1973A,B
31-1975 Grainstone, oolites, peloids, oncolites, intraclasts, algal biscuits, grapestones, brachiopods, dendroid stromatoporoids, green algae; tan; interparticle, intra-particle and moldic porosity, open; isopachus cement, some compaction.
- 1976-1978 Grainstone/packstone, peloids, stromatoporoids; tan; dolomitic calcite.
- 31-1977 Packstone, peloids, brachiopods, pelmatozoans; tan; calcite/dolomite; interparticle porosity, partially open.
- 1978-1991 Wackepackstone, brachiopods, pelmatozoans, tabulate corals; tan; dolomitic calcite.

DIVIDE COUNTY

NDGS #548

Location-Sec. 11-162N-101W

Company- Pure Oil Company

Well Name- Ole Gunderson No. 1

Formation Tops- Interlake Formation- 10922

Stonewall Formation- Not logged

Cored Interval- 10928-10985 KB- 2241

11109-11214

- 10928-10985 Mudstone; gray; dolomite; large vugular, porosity, closed; pendant cements; breccia zones.
- 10985-11109 not cored
- 11109-11119 Mudstone, peloids, intraclasts; gray; dolomite; laminations; nodular in places.
- 11119-11131 Mudstone; peloids, intraclasts; gray; dolomite; laminations; mudcracks.
- 11131-11144 Mudstone, gray and black; dolomite; breccia zones containing large intraclasts; vugular porosity, closed; geopedal mud.
- 11144-11156 Mudstone, peloids; gray and tan; dolomite, microvugular and vertical elongate porosity, open.
- 11156-11159 missing
- 11159-11167 Wackestone, intraclasts; gray; dolomite, grading upward into dolomitic mudstone; microvugular porosity, open; wispy laminations.
- 11167-11177 Mudstone, intraclasts, peloids; gray; dolomite; microvugular porosity, open.
- 11177-11188 Mudstone; beige; dolomite; thin bedded and laminated.
- 11188-11200 Mudstone, intraclasts, peloids; tan; dolomite; grades upward into gray and red dolomitic mudstone with mud infilled vugs.

- 11200-11203 Mudstone; gray; dolomite; 2-3 in diameter vugs, open; spar dolomite cement.
- 11203-11206 Mudstone; red and gray; dolomite; well laminated; large vugular porosity, open; becomes brecciated toward top.
- 11206-11207 Mudstone, intraclasts, stromatoporoids; tan (gray intraclasts); dolomite.
- 11207-11214 Mudstone; gray; dolomite
- 548-11207 Wackestone, peloids, pelmatozoans, tabulate corals, quartz silt; medium gray; dolomite; intraparticle and vugular porosity, open; most of rock is coarse crystalline dolomite.

NDGS #2010

Location- Sec. 7-163N-102W

Company- Carter Oil Company

Well Name- Dallas Moore No. 1

Formation Tops- Interlake Formation- 9610

Stonewall Formation- 10204

Cored Interval- 9611-9614 KB- 2206

9618-9638

- 9611-9612 Mudstone, intraclasts; red (tan intraclasts); dolomite.
- 9612-9614 Mudstone; red and gray; dolomite; brecciated; pink mud infill between clasts.
- 9614-9618 Missing
- 9618-9620 Mudstone; white; dolomite; with stringers of gray dolomitic mudstone.
- 9620-9622 Mudstone; gray; dolomite; vugular porosity, closed; pink peloidal mudstone infill.
- 9622-9624 Mudstone; gray; dolomite.
- 9624-9626 Mudstone; gray; dolomite; with clasts and lenses of pink dolomitic mudstone, some fractured and coated.

- 2010-9624 Dolostone, weathering pisolites, coated grains, quartz silt; medium gray; dolomite; vugular porosity, closed; spar dolomite, pendant and anhydrite cement; micritization; allochems separated from matrix.
- 9626-9629 Wackestone, peloids, intraclasts; tan; dolomite
- 2010-9628 Wackepackstone, peloids, intraclasts, quartz silt; medium gray; dolomite; fenestral porosity, closed; dolomite spar and anhydrite cement; internal sediment.
- 9629-9631 Mudstone; gray to pink; dolomite.
- 9631-9637 Mudstone, intraclasts; pink; dolomite; clasts are peloidal wackepackstone.
- 2010-9631 Packstone, peloids, intraclasts, quartz silt; medium gray; dolomitic calcite; fenestral porosity, closed; spar calcite cement; geopetal infill; anhydrite replacement; laminations.
- 2010-9635 Dolostone, weathering pisolites, quartz silt; medium gray; fenestral porosity, closed; spar dolomite cement; micritization.
- 9637-9638 Wackestone, intraclasts, peloids; gray; dolomite; wispy laminations and lenses of gray dolomitic mudstone.

DUNN COUNTY

NDGS #505

Location- Sec. 6-141N-94W

Company- Socony Vacuum

Well Name- Dvorak F 32 6P

Formation Tops- Interlake Formation- 11335

Stonewall Formation- 12010

Cored Interval- 11317-11606 KB- 2296

Note- core disordered in boxes, thin sections labeled by box number.

11317-11348 (Boxes 54 and 55) Mudstone, ferruginous nodules, ostracods, brown and red, calcite.

- 505-54-1 Wackestone, ostracods, quartz silt; tan; calcite; vugular porosity, closed and partially closed; anhydrite and spar calcite cement; neomorphic spar; stylolites; small dolomite rhombs; thin, red iron oxide crusts.
- 505-54-2 Wackestone, ostracods, quartz sand, ferruginous concretions; medium brown, red, and yellow; calcite; fenestral and vugular porosity, closed; spar calcite cement; vug lining; anhydrite replacement; pendant cement; thin crusts which are broken and recoated in large vugs.
- 505-55-3 Wackestone, ostracods; brown; calcite; intraparticle and fenestral porosity, closed; spar calcite cement; geopetal infill (ostracods, mud and peloids); wispy laminations.
- 505-54-4 Packstone, peloids, intraclasts, ostracods, quartz silt; medium brown; calcite/dolomitic calcite; fenestral porosity, closed; spar calcite cement; neomorphic spar; ostracods are concentrated in one thin layer.
- 505-54-5 Mudstone; dark brown; calcite; vugular porosity, closed; spar calcite cement; stylolites; silicification; ferruginous oolites (red); silicification associated with stylolites, also replacing dolomite rhombs.

- 505-54-5 Wackestone, ostracods, light brown and purple; calcite; intraparticle, vugular and fracture porosity, closed; spar calcite cement; stylolites; laminations; geopetal infill, horizontal and vertical fracturing.
- 505-55-1 Wackestone/packstone, intraclasts; medium brown; calcite and dolomitic calcite; interparticle, fenestral and vugular porosity, closed; spar calcite cement.
- 505-55-2 Stomatolites, flat ostracodes; tan; calcite/dolomite; vugular and fracture porosity, closed; spar calcite cement; small dolomite rhombs; silicification; ferruginous concretions; brecciation; silica replacing dolomite rhombs and some calcite cement.
- 11348-11378 (Boxes 56 and 57) Mudstone, intraclasts; red and gray-green; calcite; large vugular porosity, closed, pendant cement.
- 505-56 Packstone, intraclasts, peloids, calcispheres (?); medium brown; calcite; intraparticle, fenestral and vugular porosity, closed; spar calcite cement; pendant cement in vugs; neomorphic spar; dolomite rhombs; stylolites; dolomitization associated with stylolites.
- 505-57 Wackestone, peloids, intraclasts; light gray; calcite.
- 11378-11392 (Box 58) Mudstone; tan; calcite; vugular porosity, closed; laminations.
- 11392-11408 (Box 59) Mudstone; cream; dolomite; blue laminations.
- 11408-11456 Missing
- 11456-11471 (Box 61) Mudstone; tan; calcite; vugular porosity, closed; wispy laminations.
- 11471-11482 (Box 62) Mudstone; intraclasts; tan; calcite.
- 505-62 Mudstone, light gray; calcite, breccia porosity, fenestral porosity, closed; spar calcite cement; neomorphic spar; geopetal infill; brecciated; dolomite rhombs;

stylolites; dolomite rhombs are distributed throughout matrix but are concentrated along stylolites.

- 11482-11523 Missing
- 11523-11540 (Box 64) Mudstone; light gray and brown; dolomite; vugular porosity, closed; laminations.
- 11540-11556 (Box 65) Wackestone, intraclasts, peloids; gray; dolomite; mudstone, gray; dolomite; with thin peloidal layers and wispy laminations; and pink, chalky leached zone.
- 505-65 Breccia, clasts; medium gray; dolomite; vugular porosity, open; micritization.
- 1156-11571 (Box 66) Mudstone, tan, calcite; thin peloidal layers and wispy laminations.
- 505-66 Wackestone, peloids; light gray; calcite; pervasively stylolitized, both horse tail and solution seams; small dolomite rhombs throughout, appears "nodularized" by stylolites.
- 11571-11585 (Box 67) Wackestone, intraclasts, peloids; cream; dolomitic calcite; and mudstone; gray; calcite; wavy laminations.
- 11585-11601 (Box 68) Wackestone, intraclasts, peloids, brachiopods; gray and tan; calcite; some burrows (?).
- 505-68-1 Wackestone, peloids, quartz silt and sand, brachiopods; dark brown; calcite; small patches of oil staining; anhydrite replacement.
- 505-68-2 Wackestone, peloids, intraclasts, brachiopods, quartz silt and sand; stylolites; dolomite rhombs, burrows (?), small patches of oil staining.
- 505-68-3 Wackepackstone, brachiopods, peloids; medium brown; calcite; intraparticle porosity, closed; spar calcite cement; dolomite rhombs; stylolites; abraded and compacted fossils.

11601-11606 (Box 69) Mudstone; cream; dolomite; some mottling.

NDGS #2681

Location- Sec. 15-145N-91W

Company- Amerada Petroleum Corporation

Well Name- Jacob Huber No. 1

Formation Tops- Interlake Formation- 11210

Stonewall Formation- not logged

Cored Interval- 11310-11360 KB- 2212

11310-11312 Wackestone/mudstone, peloids, intraclasts; tan; calcite; fenestral porosity, closed.

2618-11310 Wackepackstone, peloids; tan; dolomite fenestral and vugular porosity, closed; spar calcite cement; micritization; dolomite rhombs in matrix and dolomitic allochems; calcite occurs as spar cement and micrite.

11312-11314 Wackestone, intraclasts, peloids; tan; calcite; vugular and interparticle porosity, open and closed.

2618-11313 Wackepackstone, peloids; brown/gray; calcite; fenestral and vugular porosity, closed; spar calcite cement; dolomite rhombs replacing both allochems and matrix.

11314-11317 Wackestone/mudstone, peloids; tan; calcite/dolomite.

2618-11314 Wackepackstone, peloids, intraclasts; tan; calcite; fenestral porosity, closed; spar calcite cement; dolomite rhombs; stylolites; dolomite rhombs associated with stylolites.

2618-11315 Mudstone; medium brown; dolomite; vugular porosity, closed; spar calcite cement.

2618-11316 Wackepackstone, peloids, gastropods, ostracods; red-brown; calcite; fenestral porosity, closed; spar calcite cement; shell replacement; dolomite rhombs; dolomite rhombs are tiny and are pervasive in matrix.

- 11317-11319 Mudstone; tan; dolomite; nodular.
- 2618-11318 Mudstone, quartz silt, ostracods;
red/tan; dolomite; hematite staining.
- 11319-11322 Mudstone; red; dolomite; laminated.
- 11322-11323 Mudstone; green; calcite; mottled.
- 11323-11328 Wackestone/mudstone, peloids; interparticle
vugular and fenestral porosity, open.
- 2618-11323 Mudstone, ostracods, calcispheres;
intraparticle porosity, closed; spar
calcite cement; dolomite rhombs
dispersed throughout matrix; anhydrite
replacement.
- 2618-11324 Packstone/wackestone, peloids, intra-
clasts; fenestral porosity, closed; spar
calcite cement; stylolites; large dolomite
rhombs associated with stylolites.
- 2618-11325 Mudstone, beige; calcite; fenestral
porosity; partially open; spar calcite
cement; dolomite rhombs in mudstone only.
- 2618-11326 Mudstone, ostracods, gastropods, tan;
calcite; fenestral porosity, closed; spar
calcite and baroque dolomite cement; shell
replacement; geopetal infill; dolomite
rhombs; baroque dolomite cement in fracture
porosity only.
- 11328-11332 Wackestone, peloids; tan; calcite; fenestral
and vugular porosity; closed; geopetal mud.
- 2618-11328 Wackestone; peloids, intraclasts; tan;
calcite; fenestral porosity, partially
open and closed; baroque dolomite cement;
neomorphic spar; dolomite rhombs in matrix.
- 2618-11329 Packstone, peloids, intraclasts; tan;
calcite; fenestral and intercrystal
porosity, partially open and closed; spar
calcite cement; neomorphic spar; dolomite
rhombs in matrix.
- 2618-11331 Wackestone, peloids, intraclasts; tan;
calcite; fenestral porosity, closed; baroque
dolomite cement; dolomite rhombs in matrix.

- 11332-11345 Mudstone, peloids; tan; calcite; vugular porosity, closed.
- 11345-11346 Wackestone, peloids; tan; calcite; vugular porosity, closed.
- 2618-11345 Wackestone, peloids, intraclasts; tan; calcite; intercrystal and moldic porosity, closed; spar calcite cement; mostly dolomitized.
- 11346-11360 Mudstone, peloids; tan; calcite; fenestral and vugular porosity, closed; stylolites.
- 2618-11354 Wackestone, peloids, intraclasts, tan; calcite; fenestral porosity, closed; baroque dolomite cement; dolomite rhombs in matrix.

GOLDEN VALLEY COUNTY

NDGS #470

Location- Sec. 15-140N-105W

Company- Blackwood and Nichols

Well Name- Gilman No. 1

Formation Tops- Interlake Formation- 11020

Stonewall Formation- 11501

Cored Interval- 11020-11062 KB- 2867

- 11020-11037 Breccia; tan; dolomite; vugular porosity, closed; red and green mud infill.
- 470-11026 Crystalline dolostone; vugular porosity, closed; anhydrite cement.
- 11037-11039 Breccia; gray; dolomite; with dolomitic sandstone infill similar to Ashern Fm.
- 470-11037 Breccia; gray; dolomite; breccia porosity closed; infill is quartz silt and sand similar to Ashern Fm.
- 11039-11041 Mudstone; brachiopods, gray; dolomite; vugular and moldic (brachiopods) porosity, open.
- 11041-11042 Mudstone; gray; dolomite; laminated; with breccia zone.
- 11042-11044 Mudstone; gray; dolomite; vugular porosity, open.
- 11044-11048 Mudstone, brachiopods; gray; dolomite; moldic (brachiopods) and vugular porosity, open.
- 470-11045 Wackestone, peloids, weathering pisolites; orange/yellow; dolomite; vugular porosity, closed; spar dolomite cement.
- 11048-11051 Wackestone, brachiopods, tabulate corals; gray; dolomite.
- 470-11048 Wackestone, brachiopods; medium brown; dolomite; intraparticle porosity, closed; shell replacement, geopodal infill, anhydrite replacement.

- 11051-11053 Mudstone; gray; dolomite; moldic (brachiopods) and vugular porosity, open.
- 11053-11054 Mudstone; gray; dolomite; burrowed (?).
- 11054-11056 Wackestone, tabulate coral, stromatoporoids; gray; dolomite; chert nodule.
- 470-11055 Wackestone, brachiopods, tabulate corals, pelmatozoans, fossil hash; brown; chert; silicification.
- 11056-11062 Wackestone, tabulate corals, stromatoporoids; gray; dolomite.
- 470-11056 Mudstone, tabulate corals; tan; calcitic dolomite; intraparticle porosity, closed; quartz cement; shell replacement.
- 470-11057 Boundstone, stromatoporoids, laminated; tan; dolomite; intercrystal porosity open.
- 470-11058 Boundstone, stromatoporoids, bulbous; tan; dolomite; intercrystalline porosity, open; deal oil in porosity.

MCKENZIE COUNTY

NDGS #33

Location- Sec. 12-149N-96W

Company- Amerada Petroleum
Corporation

Well Name- Ben Risser No. 1

Formation Tops- Interlake Formation- 12612

Stonewall Formation- 13002 (?)

Cored Interval- 12623-12683 KB- 2438

- 12623-12626 Mudstone, intraclasts; tan; dolomite
- 12626-12627½ Packstone, intraclasts, peloids; tan; dolomite.
- 33-12627 Wackestone; peloids, intraclasts, quartz
silt; tan; dolomite; intraparticle and
vugular porosity, open.
- 12627½-12629 Packstone, intraclasts, peloids; tan;
dolomite; thin mud beds.
- 33-12628 Packstone, peloids, intraclasts, quartz
silt, unidentified fossil; medium gray;
dolomite; interparticle porosity;
partially open; neomorphic spar.
- 12629-12630 Mudstone, intraclasts; tan; dolomite;
vugular porosity; open.
- 12630-12648 Wackestone, peloids; olive and tan; dolomite.
- 33-12623 Wackestone, peloids, quartz silt; orange;
dolomite; most of original fabric destroyed
by dolomitization.
- 33-12647 Wackepackstone, peloids, intraclasts,
quartz silt, unidentified fossil; red/brown;
calcite; fenestral porosity, closed; spar
calcite cement; geopedal infill; erosion
surface, fenestral pores below erosion
surface have geopedal muc infill, intra-
clasts in material above erosion surface
are flat chips derived from underlying
material.

- 12648-12655 Packstone/mudstone, peloids, intraclasts; tan, red and pink; calcite; some grading in packstone layers.
- 33-12648A,B Packstone, peloids, intraclasts, quartz sand and silt; reddish-brown; dolomite; fenestral porosity, closed; calcite cement; neomorphic spar; 20 percent quartz silt/sand.
- 33-12653A,B Wackepackstone, peloids, intraclasts, quartz silt and sand; light brown; calcite; fenestral and vugular porosity, closed; spar calcite and anhydrite cement; stylolites, extensive; spar cement along stylolites.
- 33-12654A,B Wackepackstone, peloids, intraclasts, quartz silt; tan; calcite; interparticle and intraparticle porosity, closed and partially open, spar cement; anhydrite replacement; dolomite rhombs.
- 12655-12660 Wackestone/mudstone, peloids, intraclasts; tan; dolomite/calcite; vugular porosity, closed; laminations.
- 33-12659 Wackestone, peloids, intraclasts, quartz silt; medium brown; dolomite; spar calcite cement; stylolites, extensive.
- 12660-12676 Mudstone, intraclasts; red, tan and gray; dolomite; burrows (?).
- 33-12663 Crystalline dolomite; vugular porosity, closed; dolomite cement; anhydrite replacement.
- 12676-12678 Grainstone, peloids; tan; dolomite.
- 33-12677 Grainstone, peloids; medium brown; dolomite; interparticle porosity, closed; spar calcite cement.
- 12678-12679 Mudstone, intraclasts; tan; dolomite.
- 12679-12680 Grainstone, packstone, mudstone, intercalated, peloids; tan; dolomite.
- 12680-12683 Mudstone, intraclasts, peloids; tan; dolomite; fenestral porosity, closed.

33-12683 Wackestone, peloids, quartz silt and sand; tan; dolomite; fenestral porosity, closed; spar calcite cement; geopetal infill; anhydrite replacement.

NDGS #147

Location- Sec. 15-152N-96W

Company- Amerada Petroleum Corporation

Well Name- George Wollan No. 1

Formation Tops- Interlake Formation- 12240

Stonewall Formation- not logged

Cored Interval- 12240-12276 KB- 2480

12240-12245 Mudstone; dark red, pink and white; dolomite.

12245-12253 Breccia; gray and brown; dolomite.

147-12245 Breccia; medium gray; dolomite; clasts composed of peloidal wackestone; vugular porosity, closed; spar calcite and pendant cement; geopetal infill, laminated.

147-12246 Wackepackstone, peloids, intraclasts, quartz silt, ostracods; medium gray; dolomite; interparticle and vugular porosity, closed; spar calcite cement; pseudospar.

12253-12256 Mudstone, peloids; tan; dolomite; fenestral porosity, closed.

12256-12273 Wackepackstone/mudstone, peloids, intraclasts; red, light brown, tan, gray and pink; dolomite; fenestral porosity, closed.

147-12268 Wackestone, peloids, intraclasts, quartz silt; tan; calcite; interparticle and fenestral porosity, closed; spar calcite cement; intraclasts are dolomite.

147-12272½ Two parts to slide- Top: Wackestone, peloids; tan; dolomite; fenestral porosity, closed; spar calcite cement; laminations. Bottom: Packstone, peloids, intraclasts, quartz silt; tan; dolomite; vugular and intercrystalline porosity, closed; dolomite pendant cement.

12273-12274 Packstone, intraclasts, peloids, gastropods;
pink and gray; dolomite.

147-12273½ Packstone, peloids, intraclasts, quartz
silt, gastropods; tan; dolomite; moldic
and vugular porosity, partially open;
spar calcite and pendant calcite cement;
thin crusts; sheel replacement.

12274-11276 Packstone, intraclasts, peloids; tan;
dolomite.

147-12275½ Wackepackstone, peloids, intraclasts,
quartz silt; tan; dolomite; interparticle
porosity, closed; spar dolomite cement.

NDGS #1606

Location- Sec. 35-150N-97W

Company- Amerada Petroleum Company

Well Name- H.H. Shelvik No. 1

Tract No. 1

Formation Tops- Interlake Formation- 12624

Stonewall Formation- not logged

Cored Interval- 12670-12923 KB- 2334

13190-13305

12670-12672 Mudstone; dark brown to black; dolomite.

12672-12675 Mudstone, peloids; tan; calcitic dolomite.

12675-12679 Mudstone; dark brown; dolomite; scour
surface.

12679-12682 Wackestone, intraclasts, peloids; brown;
dolomite.

12682-12684 Mudstone, intraclasts; brown; calcitic
dolomite.

12684-12690 Wackestone, intraclasts; brown; calcitic
dolomite.

12690-12691 Mudstone; brown; dolomite.

12691-12692 Packstone, peloids; pink; dolomite; cross
bedded.

1606-12691 Packstone, peloids, quartz silt; pink;
dolomite; thin bedded; anhydrite
replacement.

- 12692-12693 Mudstone; brick red; dolomite.
- 12693-23694 Mudstone; tan; dolomite
- 12694-12700 Mudstone; brown, gray, and tan; dolomite;
with thin layers of intraclastic wackestone.
- 12600-12701 Wackepackstone, intraclasts; tan; calcitic
dolomite.
- 12701-12706 Mudstone, trilobites; intraclasts; light
gray and pink; calcite; red wispy laminations.
- 12706-12711 Wackepackstone, intraclasts, peloids; gray;
dolomite; intraclasts coarsen upward.
- 12711-12717 Mudstone, intraclasts; light gray and pink;
calcite; wispy laminations; pyrite clots
in dolomitic laminations.
- 12717-12723 Mudstone, trilobites; black; calcite.
- 12723-12725 Wackestone, intraclasts, peloids; brown;
(intraclasts are gray and white); dolomite.
- 1606-12723 Wackestone, peloids, intraclasts; medium
brown; dolomite; fenestral porosity,
partially open; baroque dolomite cement.
- 12725-12729 Mudstone, trilobites; tan; calcite.
- 1606-12728 Wackestone, ostracods, trilobites,
unidentified fossil; light brown;
dolomitic calcite; stylolites.
- 12729-12730 Packstone, intraclasts; gray; calcitic
dolomite.
- 12730-12732 Wackepackstone, intraclasts; tan; dolomite.
- 1606-12731 Wackestone; intraclasts, peloids; dark
gray; dolomite; fenestral porosity,
partially open; spar calcite cement,
porosity in clasts only.
- 12732-12738 Packstone/wackestone/mudstone, peloids,
intraclasts; tan; calcitic dolomite.
- 12738-12741 Mudstone, trilobites; tan; dolomitic calcite.
- 12741-12743 Mudstone; tan; calcitic dolomite.

- 12743-12744 Wackestone/mudstone, peloids, intraclasts; gray; dolomite.
- 12744-12749 Wackestone, intraclasts, peloids; gray; dolomite; vugular porosity, open; dead oil; clasts are large and angular.
- 12749-12750 Mudstone; gray, dolomite.
- 12750-12752 Wackestone, intraclasts, peloids; gray; calcitic dolomite.
- 12752-12753 Mudstone; gray; dolomite.
- 12753-12769 Mudstone, trilobites; black; calcite; pyrite disseminated throughout; trilobites either dispersed throughout or concentrated in .1 inch layers; sharp contact with overlying gray mudstone.
- 1606-12754 Wackestone; trilobites, ostracods, gastropods; beige; calcite; moldic porosity, closed; spar calcite cement; shell replacement; dolomite rhombs.
- 1606-12763½ Mudstone, trilobites; black; calcite; thin beds of trilobite molts; dolomite rhombs.
- 12769-12773 Wackestone, intraclasts, peloids; tan and gray; dolomitic calcite.
- 12773-12774 Mudstone; gray and tan; calcite.
- 12774-12775 Wackestone, intraclasts, peloids; gray and tan; calcite.
- 12775-12777 Wackepackstone, intraclasts; gray and tan; calcite.
- 1606-12776 Wackestone, intraclasts; brownish-gray; dolomite; fenestral porosity; closed; spar calcite cement; erosion surface in fenestral wackestone, clasts of which are incorporated in overlying intra-clastic wackestone.
- 12777-12779 Mudstone; gray and tan; mud infilled fractures; calcite.

- 12779-12781 Packstone, peloids, intraclasts; gray; calcite and calcitic dolomite; fenestral porosity, closed.
- 1606-12779 Packstone/grainstone, peloids, coated grains, intraclasts; medium brown; dolomite; interparticle, intraparticle and fenestral porosity, open; spar calcite cement; geopetal infill; pendant cement in larger fenestral pores; small dolomite rhombs in calcite cement.
- 12781-12783 Mudstone; gray; dolomite.
- 12783-12786 Grainstone, intraclasts; gray; calcitic dolomite; clasts are rounded and pebble sized; some grading.
- 1606-12784 Grainstone, intraclasts, peloids, coated grains; black; dolomite; intraparticle porosity; partially open; anhydrite and baroque dolomite cement.
- 12786-12787 Mudstone; gray; dolomite.
- 12787-12788 Breccia; gray; dolomite; clasts are mudstone.
- 12788-12790 Mudstone; gray; dolomite; brecciated zones.
- 12790-12793 Wackestone/mudstone, peloids, intraclasts; gray; dolomite; microvugular porosity, open.
- 12793-12799 Wackestone, intraclasts; tan; dolomite.
- 1606-12798 Wackestone, peloids, intraclasts; tan; dolomite; fenestral porosity, closed; baroque dolomite and anhydrite cement.
- 12799-12800 Mudstone; gray; dolomite; microvugular porosity, open.
- 12800-12802 Wackestone, intraclasts; tan; dolomitic calcite; clasts are rounded and gray.
- 12802-12803 Grainstone, intraclasts; gray; dolomite.
- 12803-12806 Mudstone; gray; calcite; vertical tubes infilled with calcite.
- 12806-12807 Wackestone, intraclasts; tan; dolomite; clasts are angular and pebble sized.

12807-12810	Mudstone; gray and tan; calcite; laminations.
12810-12812	Wackestone, intraclasts; gray; calcitic dolomite; intraclasts are pebble sized.
12812-12813	Packstone, intraclasts; dark brown; calcite; vugular porosity, closed; mud infill.
12813-12815	Wackestone, intraclasts; gray; calcitic dolomite; intraclasts are pebble sized.
12815-12816	Mudstone; gray; dolomite; microvugular and vugular porosity, open.
12816-12820	Mudstone; tan; calcite.
12820-12821	Packstone, intraclasts; gray; dolomite; intraclasts pebble sized.
12821-12827	Wackestone, intraclasts, peloids, gray and tan; calcitic dolomite; microvugular porosity, open; vertical tubes infilled with mud.
12827-12835	Mudstone; gray; calcite.
12835-12837	Packstone, intraclasts; gray; calcitic dolomite; pebble sized intraclasts.
12837-12839	Mudstone; tan; calcitic dolomite.
12839-12844	Wackestone, intraclasts; gray; calcitic dolomite; microvugular porosity, open; pebble sized intraclasts.
12844-12848	Grainstone/mudstone, peloids; tan; calcitic dolomite.
12848-12849	Mudstone; gray; calcite; laminated.
12849-12851	Wackestone, intraclasts; gray and tan; dolomite; microvugular porosity, open.
12851-12852	Mudstone; tan; dolomite.
12852-12853	Wackestone, intraclasts; gray; calcitic dolomite; microvugular porosity, open; pebble sized intraclasts.
12853-12855	Wackestone, intraclasts, peloids; gray; dolomite; calcitic dolomite; microvugular and vugular porosity, open.

- 1606-12854 Wackestone, peloids, intraclasts; medium brown; dolomite; fenestral porosity, closed; baroque dolomite cement.
- 12885-12859 Mudstone, peloids; tan; calcitic dolomite; laminations; thin beds of peloidal grainstone.
- 12859-12863 Mudstone; gray and tan; calcitic dolomite; vertical tubes at base, mud infilled.
- 12863-12869 Mudstone, peloids; tan; calcitic dolomite.
- 12869-12871 Mudstone; gray; calcitic dolomite; vertical tubes, mud infilled.
- 12871-12872 Mudstone; gray; calcitic dolomite; vertical tubes, mud filled.
- 12872-12873 Mudstone; gray; calcitic dolomite; thin beds of peloidal grainstone.
- 12873-12877 Wackestone, intraclasts, peloids; tan; calcitic dolomite; laminated mudstone at base.
- 12877-12878 Wackestone, intraclasts, peloids; gray; dolomite.
- 12878-12883 Mudstone; tan and gray; vugular porosity, open; laminations.
- 12883-12887 Wackestone, peloids, intraclasts; tan; calcitic dolomite.
- 1606-12886 Wackestone, intraclasts; medium brown; dolomite; vugular porosity, partially open; spar calcite cement; geopetal infill.
- 12887-12888 Mudstone, peloids; gray; calcitic dolomite; fenestral porosity, open; vertical tubes, mud infilled.
- 12888-12889 Mudstone; tan; calcitic dolomite; vugular porosity, open.
- 12889-12893 Wackestone, intraclasts, peloids; tan; calcitic dolomite; intraclasts are cobble sized.
- 12893-12895 Mudstone/wackestone, intraclasts; gray and tan; calcitic dolomite; laminations.

12895-12897	Mudstone, peloids, gastropods (?), intra-clasts; gray; calcitic dolomite.
12897-12901	Wackestone, peloids; tan; calcitic dolomite; microvugular porosity, open.
12901-12902	Breccia; gray clasts, tan matrix; calcitic dolomite.
12902-12906	Mudstone; tan; calcitic dolomite.
12909-12910	Mudstone, peloids; tan; calcitic dolomite.
12911-12913	Wackepackstone, peloids; tan; calcitic dolomite.
12913-12914	Mudstone; tan; calcitic dolomite; laminated.
12914-12916	Wackestone, peloids; tan; calcitic dolomite.
1606-12915	Wackestone, peloids, intraclasts, tan; calcite/dolomite; small anhydrite blebs; stylolites.
12916-12918	Mudstone; tan; dolomitic calcite.
12918-12919	Packstone, intraclasts, peloids; tan; dolomitic calcite; intraclasts are pebble sized.
12919-12920	Mudstone; gray; dolomitic calcite.
12920-12923	Mudstone/wackestone, intraclasts, peloids; gray; dolomitic calcite; vertical tubes infilled with crystalline dolomite or dolomitic mud.
12923-13190	Not cored
13190-13191	Mudstone; brown; dolomite; laminated.
13191-13194	Mudstone; light gray; dolomite; vugular porosity, open.
13194-13201	Mudstone; brown; dolomite, vugular porosity, open.
13201-13205	Wackestone, tabulate corals (chain type); brown; dolomite.
1606-13202	Wackestone, tabulate corals; brown; dolomite; intercrystalline porosity, open; dolomite is coarse crystalline.

- 13205-13207 Mudstone; light brown; dolomite (crystalline).
- 13207-13209 Mudstone, rugose corals; dark brown; dolomite (crystalline); moldic porosity, open.
- 1606-13207 Wackestone; pelmatozoan; rugose corals; medium brown; dolomite; growth-framework porosity, partially open; stylolites; silicification, (in corals).
- 1606-13208 Wackestone, rugose corals; medium brown; dolomite; stylolites.
- 13209-13218 Mudstone; dark brown; dolomite; wavy thin beds.
- 13218-13227 Mudstone; light brown; dolomite (crystalline); wavy laminations.
- 13227-13234 Mudstone; brown; dolomite (crystalline); nodules of dolomitic mudstone (after anhydrite?).
- 13234-13236 Mudstone; brown; dolomite; bioturbated ?
- 13236-13239 Mudstone; brown; dolomite (crystalline); nodules of dolomitic mudstone (after anhydrite?).
- 13239-13242 Mudstone; brown; dolomite (crystalline); contorted laminations.
- 13242-13253 Mudstone; brown; dolomite.
- 13253-13257 Mudstone; brown; dolomite (crystalline); nodules of dolomitic mudstone (after anhydrite ?); microvugular porosity, open.
- 13257-13267 Mudstone; light brown; dolomite (crystalline); laminated.
- 13267-13268 Wackestone, intraclasts; gray; dolomite; clasts are elongate; erosion surface.
- 13268-13273 Mudstone; tan; dolomite (crystalline); well laminated.
- 13273-13276 Same as above, with vugular porosity, open.
- 13273-13277 Same as above with disturbed laminations.

- 13277-13279 Same as above with even laminations.
- 13279-13287 Same as above with disturbed laminations and thin beds.
- 13287-13292 Mudstone; brown; dolomite (crystalline); nodules of dolomitic mudstone (after anhydrite ?).
- 13292-13298 Mudstone; brown; dolomite (crystalline); laminated; and thin bedded.
- 13298-13305 Mudstone; gray; dolomite (crystalline); nodules of dolomitic mudstone (after anhydrite ?).

NDGS #6793

Location- Sec. 28-153N-95W

Company- Getty Oil Company

Well Name- E. O. and G. No. 28-9

Formation Tops- Interlake Formation- 12828

Stonewall Formation- not logged

Cored Interval- 12028-12046 KB- 2327

- 12028-12046 Wackestone; intraclasts; tan and gray; dolomite; fenestral porosity, closed; halite cement; clasts are peloidal wackestone and angular (appear collapsed); micrite crusts.

- 6793-12031 Packstone, peloids, quartz silt, intraclasts, unidentified fossils; tan; dolomite; interparticle porosity, open.

NDGS #6839

Location- Sec. 11-150N-104W

Company- Shell Oil Company

Well Name- U.S.A. No. 43-11

Formation Tops- Interlake Formation- 11828

Stonewall Formation- 12510

Cored Intervals- 11828-11854 KB- 2065.7

- 11828-11854 Mudstone/wackestone; mudstone is light brown and dolomitic, contains large dark gray clasts; Wackestone is tan and dolomitic, contains peloids and intraclasts; pin-point and microvugular porosity, open; micrite crusts.

- 6839-11842 Wackepackstone, peloids, intraclasts;
light gray; dolomite and dolomitic
calcite; fenestral porosity, partially
open; baroque dolomite cement.
- 6839-11852 Mudstone, intraclasts, peloids; gray;
dolomite; vugular porosity, closed;
crystalline dolomite cement.

McLEAN COUNTY

NDGS #49

Location- Sec. 28-150N-80W

Company- Stanolind Oil and
Gas Company

Well Name- McLean County #1

Formation Tops- Interlake Formation- 7358

Stonewall Formation- 7525 (?)

Cored Interval- 7435-7441

KB- 2100

7435-7441

Mudstone; brown; calcitic dolomite; becomes
laminated at base.

49-7435

Wackestone, peloids; brown; dolomite;
fenestral porosity, open.

49-7441

Wackepackstone, peloids, ostracods;
brown; dolomite; moldic porosity,
partially open; anhydrite and spar
calcite cement; stylolites; anhydrite
replacement.

WELLS COUNTY

NDGS #207

Location- Sec. 27-145N-73W

Company- Continental Oil Company

Well Name- Lueth #1

Formation Tops- Interlake Formation- 4660

Stonewall Formation- 4878

Cored Interval- 4660-4826

KB- 1933

4660-4676

Breccia; tan; dolomite; clasts are laminated (algal ?).

4676-4706

Ferruginous mudstone, ferruginous concretions;
red; dolomite; iron oxides.

4706-4718

Mudstone; gray; dolomite; laminated (algal);
some flat chip horizons.

4718-4745

Mudstone, intraclasts, peloids; tan; dolomite; zones of peloidal packstone and grainstone; fracture surfaces covered with euhedral pyrite; also filled with coarse crystalline anhydrite.

207-4721

Packstone, peloids; tan; calcite; moldic porosity, open; anhydrite fracture fill.

4745-4752

Mudstone, pink and purple; dolomite; with 1 mm white dots.

4752-4777

Wackestone, brachiopods, rugose corals,
tabulate corals; tan; calcitic dolomite.

207-4761

Wackestone, brachiopods, peloids; tan;
dolomitic calcite.

4777-4812

Mudstone, light purple, dolomite, with red and white 1 mm dots.

4812-4826

Wackestone, brachiopods; tan; calcitic dolomite; brachiopods can only be seen as casts on the broken ends of core.

207-4816

Wackestone, pelmatozoans, peloids; tan;
dolomitic calcite; stylolites.

WILLIAMS COUNTY

NDGS #25

Location- Sec. 6-155N-95W

Company- Amerada Petroleum Company

Well Name- Clarence Ivorson No. 1

Formation Tops- Interlake Formation- 11628

Stonewall Formation- not logged

Cored Interval- 11628-11743 KB- 2219

11628-11637 Breccia; gray and tan; dolomite; clasts are large; vugular porosity, closed; dolomitic pendant cement.

25-11637 Breccia, intraclasts, coated grains;
brown and gray; dolomite; vugular
porosity closed; spar calcite, spar
dolomite and pendant dolomite/calcite
cement.

11637-11639	Missing
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11639-11649 Wackestone, peloids; gray; dolomite;
brecciated at top.

11649-11657 Wackepackstone, peloids; tan; dolomite;
vugular porosity, closed; halite cement.

11657-11658	Missing
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11659-11664 Mudstone; gray; dolomite; laminated.

11664-11669	Missing
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11669-11679 Wackestone/mudstone, intraclasts; gray;
dolomite.

11679-11689 Wackestone; intraclasts; gray; dolomite;
becomes burrowed at base.

11689-11699 Mudstone; peloids; gray; dolomite, thin beds
of peloidal packstone; fenestral porosity,
open; vertical stylolites.

- 11699-11709 Mudstone, intraclasts; gray; dolomite; clasts are pebble sized; grades into peloidal intraclastic packstone at top.
- 11709-11714 Mudstone/wackestone; intraclasts; gray; dolomite.
- 11714-11724 Mudstone, intraclasts; tan; calcite/dolomite; fenestral and vugular porosity, open.
- 11724-11734 Mudstone/wackestone, peloids; tan; calcite/dolomite; vugular porosity, open; one thin fossiliferous bed.
- 25-11724 Wackepackstone, intraclasts, peloids, ostracods; light brown; calcite; fenestral porosity, closed; spar calcite and pendant calcite cement; geopetal infill; dolomite rhombs.

NDGS #32

Location- Sec. 12-157N-97W

Company- Amerada Petroleum Company

Well Name- Bakken No. 1

Formation Tops- Interlake Formation- 11561

Stonewall Formation- 12555

Cored Intervals- 11556-11588 KB- 1782

11603-11664

12361-12376

12481-12516

12550-12583

- 11556-11562 Breccia; red and pink; dolomite.
- 11562-11565 Grainstone/wackepackstone, peloids, intraclasts; gray; dolomite; solutioning.
- 32-11563 Breccia, weathering pisolites; medium gray; dolomite; vugular and breccia porosity, closed; anhydrite, spar dolomite and silica cement; anhydrite and silica replacement; micrite coatings.
- 11565-11569 Grainstone, intraclasts, peloids, gray dolomite; vugular porosity, closed; brecciation.
- 32-11568 Breccia; medium gray; dolomite; peloids in clasts; vugular porosity, closed; baroque dolomite and pendant dolomite cement; micrite coated grains; silicification of dolomite cements.

- 11269-11571 Packstone, intraclasts; gray; dolomite.
- 32-11569½ Packstone, peloids, intraclasts, unidentified fossils; gray; dolomite; fracture, breccia and vugular porosity, partially open; spar dolomite and pendant dolomite cement; micritization.
- 11571-11578 Wackestone, peloids, intraclasts; gray; dolomite; intraparticle and vugular porosity, closed.
- 32-11573 Wackepackstone, peloids, intraclasts, quartz silt; gray; dolomite; vugular porosity, partially open; spar dolomite, baroque dolomite and pendant dolomite cement, brecciated.
- 32-11574 Breccia; gray; dolomite; breccia and vugular porosity, closed; spar dolomite baroque dolomite and pendant dolomite cement; silicification.
- 11578-11580 Packstone/wackestone, intraclasts; gray; dolomite; vugular and interparticle porosity; closed.
- 32-11578 Packstone, quartz sand and silt, peloids, intraclasts, unidentified fossils; gray; dolomite; vugular porosity; closed; baroque dolomite and pendant dolomite cement; silicification.
- 11580-11581 Wackestone, peloids, gastropods; gray; dolomite; moldic porosity, open.
- 32-11581 Wackepackstone, peloids, intraclasts, gastropods, quartz silt and sand; moldic porosity, open; anhydrite and spar dolomite cement.
- 11581-11583 Wackestone, peloids; gray; dolomite; vugular porosity, closed.
- 11583-11586 Wackestone, peloids; gray; dolomite; desiccation cracks.
- 32-11585½ Wackepackstone, peloids, intraclasts; gray; dolomite; vugular and fracture porosity, closed; spar dolomite cement.

11586-11588	Mudstone, peloids; gray; dolomite.
11588-11603	Not cored
11603-11605	Wackestone, peloids, intraclasts; brown; dolomite.
11605-11606	Mudstone; brown; dolomite.
11606-11608	Wackestone, intraclasts; dark gray; dolomite; bioturbated (?).
32-11606½	Wackestone, intraclasts, peloids; brown; dolomite; vugular porosity, partially open, spar dolomite and pendant dolomite cement.
11608-11609	Mudstone; brown; dolomite.
11609-11618	Mudstone; brown; dolomite; bioturbated.
32-11616	Mudstone, peloids, ostracods; gray; dolomite; vugular porosity, closed; spar dolomite cement; anhydrite replacement; silicification; shell replacement.
11618-11624	Mudstone, peloids; gray; dolomite, thin beds of peloidal wackestone.
32-11618	Packstone, peloids, quartz silt; gray; dolomite; dolomite rhombs.
11624-11626	Wackestone, peloids; gray; dolomite; burrows and desiccation cracks.
11626-11628	Mudstone; gray; dolomite.
11628-11634	Wackestone, intraclasts; dark gray; dolomite.
32-11631	Mudstone, coated grains; gray; dolomite; vugular porosity, closed; pendant dolomite cement.
11634-11649	Mudstone/wackestone; peloids, intraclasts; tan; dolomite; burrowing.
11649-11650	Wackepackstone, intraclasts; tan; dolomite.
32-11649½	Packstone, peloids, intraclasts, quartz silt, ostracods, unidentified fossil; tan; dolomite; vugular porosity, partially open; spar dolomite cement; dolomite rhombs.

11650-11651	Mudstone; tan; dolomite.
32-11650½	Crystalline dolostone, peloids (?); tan.
11651-11655	Wackestone/mudstone, intraclasts; tan; dolomite.
11655-11657	Mudstone; tan; dolomite.
11657-11659	Wackestone, intraclasts, peloids; tan; dolomite.
11659-11661	Mudstone, peloids; tan; dolomite.
11661-11665	Wackepackstone, peloids; tan; dolomite.
32-11664	Wackepackstone, peloids, intraclasts, quartz silt; tan; dolomite; allochems are squashed.
11665-12361	Not Cored
12361-12364	Mudstone; brown; dolomite.
12364-12365	Mudstone; brown; dolomite; laminated.
12365-12371	Anhydrite and brown dolomititic mudstone, anhydrite is massive bedded and mudstone is laminated.
12371-12375	Anhydrite and brown dolomititic mudstone, anhydrite is distorted nodular and bedded mosaic.
12375-12376	Mudstone; dark brown and light brown; dolomite; laminated.
32-12375	Stromatolite, flat, medium brown; dolomite; vugular porosity, closed; anhydrite cement; anhydrite replacement.
12376-12481	Not cored
12481-12484	Mudstone; brown; dolomite; laminated.
32-12483	Mudstone; quartz silt; medium brown; dolomite; thin beds; distinct burrows.

- 12484-12498 Anhydrite and brown dolomitic mudstone; anhydrite is massive bedded, nodular and bedded mosaic.
- 32-12489½ Anhydrite and brown dolomitic mudstone; thin interbeds.
- 12498-12505 Anhydrite and brown dolomitic mudstone; interlaminated.
- 32-12498 Anhydrite and brown dolomitic mudstone; interlaminated.
- 12505-12516 Mudstone; brown; dolomite.
- 32-12515 Mudstone; brown; dolomite; large desiccation crack, with laminated coatings.
- 12516-12550 Not cored
- 12550-12565 Mudstone; brown; dolomite.
- 32-12551 Mudstone, peloids, quartz silt; brown; dolomite; laminated.
- 12555 Contact Stonewall
- 12565-12568 Wackestone, pelmatozoans, brachiopods, trilobites, gastropods; brown; dolomitic calcite.
- 32-12565 Wackepackstone intraclasts, pelmatozoans, brachiopods, trilobites, ostracods; brown; calcite; syntaxial cement; neomorphic spar; dolomite rhombs; stylolites; allochems are imbricate and abraded.
- 12568-12572 Anhydrite and brown dolomitic mudstone; anhydrite is massive.
- 32-12571 Anhydrite and brown dolomitic mudstone; stylolites.
- 12572-12574 Anhydrite and brown dolomitic mudstone; anhydrite is bedded mosaic.
- 12574-12578 Mudstone/wackestone, intraclasts; dark gray; dolomite.
- 12578-12583 Anhydrite and dark gray dolomitic mudstone; anhydrite is bedded mosaic and massive bedded.

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